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ALLEN THOMSON, M.D.

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CIRCULATION.

CIRCULATION (in Physiology), *(Circulatio, Circulus, Circuitus Sanguinis;* Fr. *Circulation du Sang;* Germ. *Blutlauf;* Ital. *Circolazione del Sangue;)* designates in its more extensive signification the course through organised beings of their nutritious fluid; as limited to man and the higher orders of animals, the course of the blood from the heart to the most minute vessels, and from these back to the heart.

By modern writers on physiology the circulation of the blood is generally included under the nutritive functions, because one of the most important purposes served by the motion of this fluid through the various textures and organs of the body is the supply of those new ingredients which are necessary to carry on the process of growth and the changes of nutrition. A very slight acquaintance with animal physiology teaches us, however, that the function of circulation has another very important and immediate use, viz. the support of that condition of the textures and organs which is necessary to enable them to exercise their vital properties. It was on account of the apparent necessity of a constant supply of blood for the support of the animal powers, that Galen placed circulation, along with respiration, among the vital functions.

In the following article it is intended to describe more particularly the course of the blood in the human body and the powers by which it is moved, and also to state the general facts ascertained regarding the function of circulation in other animals.

For the sake of clearness it will be necessary to divide the subject into several departments. The first of these will comprehend a description of the course of the blood in man; the second of its course in animals. In the third will be considered the phenomena presented by the blood during its motion, the properties of the organs in which it circulates, and the powers by which it is propelled; and in the fourth will be mentioned the more important circumstances connected with the other functions which modify the circulation.

The term circulation applied by its celebrated discoverer, Harvey, to the motion of the blood, is sufficiently expressive of the general fact that this fluid, or the greater part of it at least, in being carried through the body, moves in a circular course, or, that in performing its journey through the body, the blood always returns to the same place from which it set out. The term is equally applicable to the function by which a supply of nutritious fluids is kept up in the lowest animals, in which a progressive motion of a fluid of the nature of blood takes place, as well as in the highest; for in nearly the whole of them there is a central part of the circulatory organs, which forms the rallying point, as it were, of the rest, from which the blood begins its course and to which it is brought back, in a longer or shorter period of time, after having passed through the different organized parts.

I. Course of the blood in man.

The organs of circulation consist of the heart, arteries, veins, and capillary vessels. We refer the reader to the articles on these different organs for all details relative to their anatomical structure.

In man and warm-blooded animals there are two passages through the interior of the heart, through each of which a stream of blood is propelled at the same time, so that the heart is alternately receiving and giving out a certain quantity of blood upon each side.

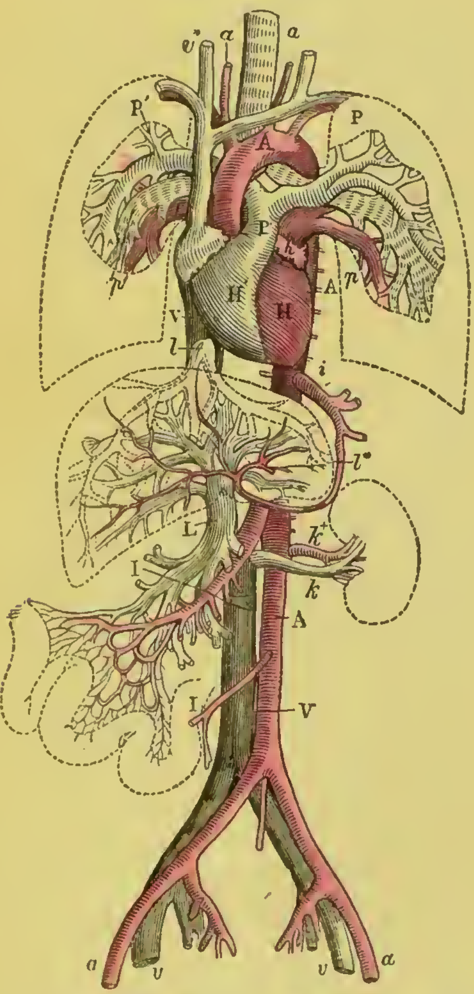
The two auricles serve as receiving cavities for the blood which is constantly flowing into the heart from the veins or those vessels which have the office of returning blood to the centre of the circulation. By the contraction of the muscular parietes of the auricles, the blood is propelled from these cavities into the ventricles, which, in their turn, contract with force and thus propel their contents into the arteries, or those vessels which serve to transmit blood outwards from the centre of the circulatory organs. The auricles and ventricles of the opposite sides acting simultaneously, and the size of these cavities on the right and left sides of the heart being nearly equal, the quantity of blood which is made to pass through each of them at one and the same time must also be nearly equal.

The cavities on the left side of the heart are adapted to propel the blood into those arteries which are subservient to the nutrition of the body, while those on the right side of the heart send the blood to the lungs for the purposes of respiration. The construction of the heart and the connection of its parts with the arteries and veins are such that the whole of that blood which has served the purposes of nutrition, and the other uses for which the blood is destined throughout the body, on being returned to the heart, is directed by the cavities on the right side of that organ to the lungs, and made to pass through them before returning to the left side of the heart to repeat its course through the nutritive vessels of the body.

In all those animals in which there exists a disposition of the heart and bloodvessels such as that described, the circulation is said to be *double,* because the blood is moved in two circles at once, and the respiration is said to be *complete,* because the whole of that blood which has passed through the nutritive vessels of the body is subjected to the respiratory action of air in the lungs.

The blood returned from the lungs of a bright red colour, or arterial blood, on being expelled from the left ventricle *(fig.* 1, *H)* by the muscular contraction of that cavity, passes into the aorta or great artery of the system (*A*), and is distributed in various proportions to all parts of the body by the branches of the aortic trunk (*a*) and their infinitely minute ramifications. The smallest arteries lead, by an intermediate set of minute tubes to which the name of capillary vessels is given, into the systemic veins (*v*), all of which (the veins of the intestinal canal excepted) joining gradually together into larger and fewer branches, form at last the great trunks of the superior and inferior venæ cavæ (V, v^*), which carry back to the centre of the circulation the whole of the blood that had passed from the left ventricle into the aorta.

Fig. 1.*



Circulation in Man.

In passing from the arteries to the veins through the capillary vessels, the properties of the arterial blood are changed; its colour is altered from bright scarlet to dark purple, it expends some of its substance in the nourishment of the textures, and a considerable quantity of its thinner part transudes through the small vessels, constituting the lymph that is taken up by the absorbent vessels. The venous or dark blood, as it approaches the heart upon its return, has its composition further changed by its admixture with the chyle or imperfectly formed blood, which is the product of digestion, and which is poured along with the lymph from the thoracic duct into the great veins of the head and superior extremities.

By the changes thus produced in its composition, &c., the venous blood which returns to the heart is rendered unfit for nutrition, until it has been acted upon by the atmospheric air in the lungs, which restores to it its bright red colour and arterial composition and properties.

The great systemic veins are therefore connected with the right side of the heart (*H'*), and the stream of venous blood brought by them to the right auricle (*h'*), next issues from the heart by the pulmonary artery (*P*), into which it is propelled by the contraction of the right ventricle *(H')* as it passes through that cavity. The minute branches of the pulmonary arteries and veins *(P, p),* and the capillary vessels by which they communicate with one another, are wholly distributed on the membrane lining the air-cells of the lungs. In passing through these vessels then, the venous blood is exposed to the action of the atmospheric air contained in the pulmonary cells; and, after having acquired arterial properties, is returned to the centre of the circulation by the pulmonary veins (*p*). The left auricle (*h*) receives the newly arterialized blood from the pulmonary veins, and transmits it to the left ventricle (*H*), from which it is ready to start again, when the ventricle contracts, on the same course as has just been described.

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* In all the figures relating to the circulation in different animals the same letters indicate corresponding parts as follows :

- *H,* the heart or the common ventricle ; *h,* the common auricle ;
- *A,* the aorta or trunk of the systemic arteries ; *a,* its branches ; a^*, the carotids.
- *V,* the great systemic veins or vena cava inferior ; *v,* its branches ; v^*, the vena cava superior ; *c,* the capillary vessels ;
- *P,* the pulmonary artery ; *p,* the pulmonary vein ;
- *B,* the branchial artery ; *b,* the branchial vein ;
- *D,* the ductus arteriosus ; *d,* ductus venosus ; *f,* foramen ovale ;
- *U,* umbilical arteries ; *u,* umbilical vein ;
- *I,* arteries of the intestine or alimentary canal ; *i,* the cœliac artery ;
- *L,* vena portæ ; *l,* hepatic vein ; l^*, hepatic artery ;
- *K,* advehent renal veins ; *k,* renal veins ; k^*, renal artery.

In those instances in which the parts are double, those on the right side are distinguished by the accentuation of the letters indicating them, thus P′ right pulmonary artery, P left ditto.

We beg to remind the reader that most of these figures are merely plans, and that strict anatomical accuracy is not to be looked for in them.

In this double circulation, the path which the blood traverses in passing from the left to the right side of the heart through the aortic arteries and the corresponding veins, has been called the *greater* or *systemic* circulation: and the route of the blood from the right to the left side of the heart through the pulmonary arteries and veins has been termed the *lesser* or *pulmonic* circulation. The names of pulmonic and systemic, indicating the parts of the body in which each of these circulations respectively occurs, are on the whole preferable to the corresponding terms of lesser and greater.

There is still one part of the course of the blood to be mentioned, viz. that of the venous blood of the principal abdominal viscera through the liver, or what has been termed the system of the vena portæ.

The blood supplied by the cœliac and mesenteric arteries (*I*, *i*) to the abdominal viscera is not returned directly to the heart by their corresponding veins, as occurs in other parts of the body. The veins of the stomach and intestinal canal, of the spleen, pancreas, mesentery, omenta, and gall-bladder, unite together below the liver into one large vessel (*L*), the trunk of the vena portæ, which branches out again and distributes to the liver by its ramifications the whole of the venous blood coming from the above-mentioned organs. The blood of the vena portæ, being joined in the minute branches by that of the hepatic artery (*l**), passes into the smallest ramifications of the hepatic veins, by the principal trunks of which (*l*), the venous and arterial blood circulated through the liver is carried to the inferior vena cava, and thus reaches at last the right side of the heart.

Proofs of the circulation.—After this brief outline of the course which the blood takes through the circulatory organs in man and warm-blooded animals, it may be proper to introduce an enumeration of those circumstances which are generally adduced as affording the most satisfactory "proofs of the circulation" or evidence that the blood pursues the paths above detailed.

As proofs of the circulation, besides those derived from the connection of the different orders of great vessels with the cavities of the heart to which they are respectively attached, may be mentioned—

1st. The structure and disposition of the auriculo-ventricular valves of the heart, and semilunar valves of the aorta and pulmonary artery, which admit of the passage of blood from the auricles to the ventricles, and from the latter cavities to the great arteries, but not in a reverse direction.

2nd. The mechanism of the valves of the systemic veins which allow of the motion of fluid only in the direction towards the heart.

3rd. The fact that when a ligature is applied to an artery, or any other impediment opposed to the free passage of blood through it, the vessel becomes dilated on the side next the heart, while the application of a ligature to the trunk of a vein is followed by a turgescence of the vessel beyond the place where the obstruction occurs.

4th. That on opening one of the larger arteries, blood issues in a jet from the end next to the heart at the time of every contraction of that organ, and that in general no blood flows from the orifice of the remote part of the artery: and that on opening a vein the converse is observed, the blood issuing freely in a continued stream from the remote part, but none proceeding from the part of the vein adjoining the heart.

5th. That the passage of the blood from the arteries to the veins in the small or capillary vessels has been observed by means of the microscope in transparent parts of animals, and, though it has not been seen in man, we are entitled from the general analogy in the structure of the organs of circulation to infer that the same passage occurs in the human body.

6th. That, by mechanical arrangements, fluids may easily be made to pass in the dead body through the whole course of the double circulation, but not in a direction different from that which the blood has been stated to pursue.

7th. That by the operation of transfusion, the blood of one animal may be made to circulate through the heart and vessels of another, by connecting together the bloodvessels (whether arteries or veins) of the two animals, in such a manner that the course in which the blood is directed by the action of the heart of the animal from which the blood is derived is that of the natural circulation in the animal into which it is introduced.

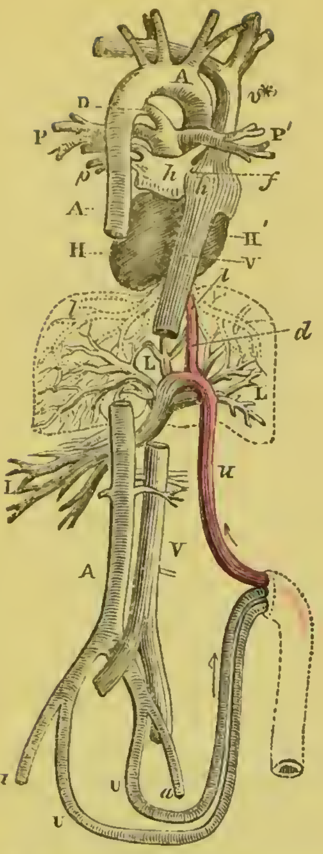
8th. The phenomena presented by the circulation of the blood in various diseased conditions of the heart and bloodvessels may be adduced as affording additional illustration of the natural course of the blood, by pointing out the effect of morbid obstructions and other varieties in different parts of the circulatory organs.

Course of the blood in the fœtus before birth.—The double circulation just described is the course performed by the blood from the time of birth during the whole of life.

The circulation of the blood, however, begins at a very early period of fœtal life; but the difference in the mode in which respiration is effected in the child so long as it is contained in the uterus, induces a modification in the course of the blood to which we shall now advert.

There being no inhalation of air into the lungs of the fœtus, the blood is sent only in small quantity to these organs, and does not undergo in them any change of properties. A considerable portion of the blood of the fœtus passes out of its body through the umbilical cord (*fig.* 2, *U*, *u*) into the placenta of the uterus. The minutely divided fœtal vessels are bathed by the blood of the mother contained in the placental sinuses, and, though no direct

Fig. 2.



Fœtal circulation seen from behind.

continuity of tube exists between the maternal and fœtal vessels, the blood of the child seems to undergo a respiratory alteration, or a certain degree of arterialization, in being brought into near proximity with the maternal blood.

The blood of the fœtus, after passing through the minute ramifications of the umbilical arteries *(U′, U)* in the placenta, returns by the umbilical vein (*u*) into its body.

The umbilical vein carries part of its blood directly by the ductus venosus (*d*) to the vena cava inferior, and part is distributed by the branches of the vena portæ *(L)*, with which the umbilical vein unites, through the substance of the liver, and is then conveyed by means of the hepatic veins (*l*) into the general current of the returning blood.

The right auricle of the heart (*h′*), therefore, receives not only the blood which has circulated through the body of the fœtus, but also that which has passed through the placenta, consequently a mixture of venous and arterial blood;—the blood in the superior vena cava (v^*) being entirely venous, that in the inferior vena cava *(V)* being mixed. The blood which is brought to the right auricle is in much greater quantity in the fœtus before birth than in the child which has breathed air; a part of this blood passes from the right into the left auricle (*h*) by the foramen ovale (*f*) in the septum auricularum, and it would appear that it is chiefly the blood from the inferior vena cava which takes that course.

The rest of the blood entering the right auricle takes the same route as in the adult, viz. into the right ventricle *(H′)*, and thence into the pulmonary artery, but, as very little blood is sent to the collapsed lungs, a passage of communication is established in the fœtus from the pulmonary artery into the descending aorta through the ductus arteriosus *(D)*, and thus the greater mass of the blood, which in the adult would have proceeded to the lungs, is in the fœtus immediately transmitted to the aorta *(A)*.

From the disposition of the Eustachian valve, it is believed that nearly the whole of the blood of the inferior vena cava passes from the right to the left auricle through the foramen ovale, while the blood brought from the head and superior extremities (parts which are comparatively large in the fœtal condition) passes through the right side of the heart. The ascending aorta, rising from the left ventricle, delivers almost all the blood expelled by the contraction of that cavity into the carotid and subclavian arteries, while the ductus arteriosus passing between the trunk of the pulmonary artery and the descending aorta directs the blood which passes through the right ventricle to the lower regions of the body. In this manner the upper regions of the body are supplied with the most arterialized part of the blood from the left side of the heart and aorta, while the purely venous blood is propelled from the right ventricle through the pulmonary artery and ductus arteriosus into the descending aorta, and consequently into the lower part of the body, and by the umbilical vessels to the placenta.

The foramen ovale in the septum of the auricles, the ductus arteriosus passing from the pulmonary artery to the aorta, the ductus venosus leading from the umbilical vein to the vena cava inferior, and the umbilical vein and arteries are the structural peculiarities of the fœtal circulating organs. These passages are all closed up, and the umbilical vessels obliterated at the navel after aerial or pulmonic respiration is established at birth.*

II. COURSE OF THE BLOOD IN VARIOUS ANIMALS.

We now leave for the present the history of the circulation in man, in order to give a brief sketch of the varieties of this function in other animals, the study of which is calculated to throw considerable light upon some of the processes of the human economy, and to illustrate the anatomical and physiological relations of the circulatory and respiratory organs.†

It has been shewn that a regular and progressive circulation of the nutritive fluids occurs in those animals only in which the aeration of the blood is performed by a separate and distinct respiratory apparatus; and that, amid the immense varieties of form which the circulatory organs present in different animals, the course of the blood bears a more close relation in all to the form of their respiratory apparatus than to any other part of their organization. This general law of the relation between circulation and respiration, satisfactorily established by the extended researches of modern comparative anatomists, receives farther confirmation from many facts connected with the performance of these functions in the adult human body, and is illustrated in a peculiar manner by the remarkable changes which take place in the circulatory and respiratory organs of the child before and after birth.

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* Sabatier, Mém. de l'Acad. An 8. Kilian, Kreislauf im Kinde, &c. Karlsruhe, 1826. Burdach's Physiologie, &c. vol. ii. Jeffray, Peculiarities of the Fœtal Circulation. Glasgow, 1834.

† In the following view of the comparative physiology of the circulation, besides the different works referred to under the separate heads, we have been guided chiefly by the following, viz. the works of Cuvier, Home, Meckel, Blumenbach, Treviranus, Carus, and R. Wagner; Roget's Bridgewater Treatise, and the excellent chapter upon this subject by J. Müller in Burdach's Physiologie, vol. iv. and in his Handbuch der Physiologie, vol. i.

In treating of the varieties in the course of the blood in different animals, we are at once freed from any embarrassment regarding the order proper to be pursued, by the circumstance that the form of the circulatory organs constitutes one of the principal bases upon which the modern classification of animals is founded; so that, in following the zoological arrangement, we take the order best adapted for our present purpose. As our object in giving this sketch is principally to illustrate the structure and functions of the human organs of circulation, we shall begin with the consideration of the course of the blood in those animals which most nearly resemble man; and trace the varieties in this function, as far as our knowledge permits, through the descending series of the animal chain.

1. *Course of the blood in warm-blooded animals.*—In Mammalia and Birds, the form of the organs of circulation and the course of the blood are essentially the same as in Man, for in all of these animals the heart contains four distinct cavities,—two auricles and two ventricles, and there is consequently a double circulation and a complete respiration.

Some considerable varieties in the form of the circulatory organs, which seem to have a relation to peculiarities in habits or mode of life, occur in certain mammiferous animals, such as the Cetacea, Amphibious Carnivora, the Sloths, Hybernating Animals, &c.; but we shall not at present enter upon the consideration of these varieties, because they do not amount to any deviation from the type or general plan of construction of the human organs of circulation, and consequently are not accompanied by any material difference in the course of the blood, but seem rather to have the effect merely of modifying the quantity of blood sent to particular organs, or of influencing its velocity and force.*

In the organs of circulation of the various tribes of Birds, we observe the same remarkable uniformity of structure which pervades the rest of their internal organization.

It may be remarked that, as in Birds a certain respiratory action takes place in the large air-cells distributed over the trunk of the body, and as the pulmonary vessels seem in most birds not to extend to these cells, but to be confined to the thoracic lungs, the blood contained in the small branches of the systemic arteries and veins, ramifying upon the lining membrane of the air-cells, must be made to undergo some respiratory alteration of its composition; but we have not as yet obtained the means of judging accurately of the extent to which such a respiratory change may be effected in the vessels of the systemic circulation, nor how far the minute branches of the pulmonary vessels may in some instances be prolonged from the lungs into the air-cells.*

Very frequent anastomoses take place among the veins of Birds. We may here mention one of these which induces an important modification in the portal circulation. By means of a communicating branch which passes from the united caudal, hemorrhoidal, and iliac veins to the vena portæ, the blood of the viscera of the abdomen and of the posterior part of the body may flow indifferently either into the vena cava inferior or the vena portæ, a disposition which may have for its object to prevent congestion of blood in the parts from which these veins proceed.†

A still more remarkable modification of the venous circulation in Birds was supposed to exist by Professor Jacobson of Copenhagen, consisting in the distribution of branches of the vena cava inferior to the interior of the kidneys and their subdivision in these organs, in the same manner as the vena portæ subdivides in the liver. Such veins transmitting venous blood to the kidneys, in the manner of a vena portæ, have been ascertained by Professor Jacobson,‡ and are admitted by others making subsequent researches, to exist in Reptiles and Fishes; but Nicolai§ has shewn that the lower veins, described by Jacobson in Birds as *venæ advehentes* of the kidney, do not differ from the other branches of the vena cava, and serve to carry away from these organs, like the superior renal veins of Birds and the renal veins of Quadrupeds, the venous blood derived from the arteries.

Course of the blood in cold-blooded vertebrated animals.—Of cold-blooded vertebrated animals, some, as the adult Batrachia, Chelonia, Ophidia, and Sauria, breathe air by means of lungs, while the rest, as the young Batrachia, the Protean, and Siren-like Reptiles and Fishes, are constant inhabitants of water, and breathe the air contained in that medium by means of gills or branchiæ. Of the aquatic cold-blooded animals, Fishes breathe by gills only, while the aquatic Reptiles or Amphibia are furnished with lungs as well as gills during the greater part of their aquatic life.

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* See p. 43.

* See the article Aves, p. 330.

† It is a remarkable fact that there have been found, between the hemorrhoidal veins in Man and some branches of the vena portæ, anastomoses by small branches, which correspond in some respects with the disposition of the veins referred to above. These anastomoses were known to Haller, and are lately described by Retzius. See his Researches in Tiedemann's and Treviranus' Zeitschrift, vol. v. 1.

‡ Meckel's Archiv. vol. iii. p. 147. Edin. Med. and Surg. Journ. vol. xix. p. 78.

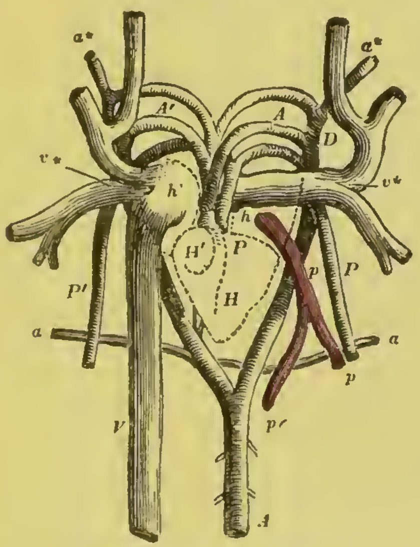
§ Isis, 1826, p. 414.

Reptiles.—The structure and functions of the circulatory organs in Reptiles form a subject of great interest on account of the numerous varieties which they exhibit in different orders and genera, for in this respect the class of Reptiles may be said to present to us an anatomical analysis of the circulatory and respiratory organs, and to constitute a gradually simplifying series of forms, the observation of which enables us to trace in the most clear and interesting manner an analogy and correspondence between the forms of these organs in warm-blooded animals and in fishes, which, but for the study of their structure in reptiles, must very probably ever have remained hidden from our view.

In Fishes the heart consists of one auricle and one ventricle, and a single current of blood only passes through it. The structure of the heart is very similar in some of the Batrachia breathing by gills, but among other reptiles, we find a gradual transition in the form and structure of the heart from that just mentioned as peculiar to animals with aquatic respiration, to the double heart possessed by warm-blooded and air-breathing animals.

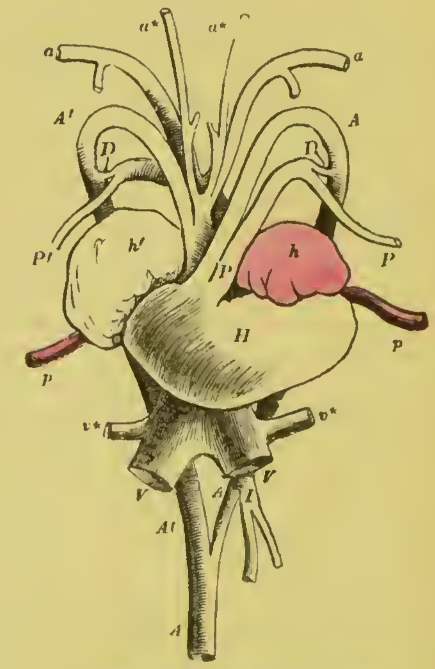
Among the Reptiles provided with lungs and breathing air, some, as the Sauria, Ophidia, and Chelonia, have the ventricular part of the heart partially divided into two cavities (*fig.* 3, *H, H'*) which correspond in structure, relative situation, and connections to the right and left ventricles of the heart of warm-blooded vertebrata; the anterior or right compartment (*H'*) giving off chiefly the pulmonary (*P*), the left or posterior (*H*), the systemic arteries (*A*). In the others, viz. the Batrachia and Protean reptiles, the ventricle forms a single cavity (*figs.* 6 and 7, *H*), and gives origin to one large artery only (*A*), so that the pulmonary and systemic arteries derive their blood from the same trunk. In all of these, however, the auricle is double,[*] so that the venous blood from the system and the arterial blood from the lungs are received into separate auricular compartments of the heart, and are subsequently mingled together in the common ventricular cavity. In the Heart of the Crocodile of the Nile, Cuvier[*] has described three compartments, one of which corresponds to the left, the other two to the right ventricle, the septum between the right and left sides being incomplete. The heart of the Crocodilus Lucius is described by Hentz, Meckel,[†] and others as consisting of two ventricles, between which the septum is quite complete, so as to permit of no direct passage of fluid from one side to the other, possessing therefore in this respect, the same structure as the heart of warm-blooded animals. In those of the above-mentioned reptiles in which the septum is so nearly complete as to divide the ventricle into two separate compartments communicating by a small orifice, the arterial and venous blood are believed to be kept separate from one another by a valvular apparatus. Among the rest of the Saurian, Ophidian, and Chelonian Reptiles, in all of which the septum of the ventricular part is less complete than in the Crocodile, there is considerable variety in the extent to which the division of the cavity is effected by the septum. In a few of them the septum projects so little into the ventricular cavity that it cannot be supposed to divide to any extent, or to prevent the complete mixture of the two kinds of blood propelled from the opposite auricles.

Fig. 3.



Heart of Lacerta ocellata.

Fig. 4.



Heart of Common Tortoise.

In the Crocodile, and in those Reptiles in which the ventricular septum is nearly complete, the circulation, so far as regards the heart at least, may be considered as almost double, or the same as in warm-blooded animals, that is to say, the arterial blood returning from the lungs to the left auricle *(fig.* 3, *h)* is directed entirely into the arteries of the system *(A)* from the left compartment of the ventricle *(H)*, and the venous blood brought back to the right auricle *(h')* by the venæ cavæ *(V v**) is directed wholly into the pulmonary vessels *(P)* by the right ventricular compartment *(H')*.

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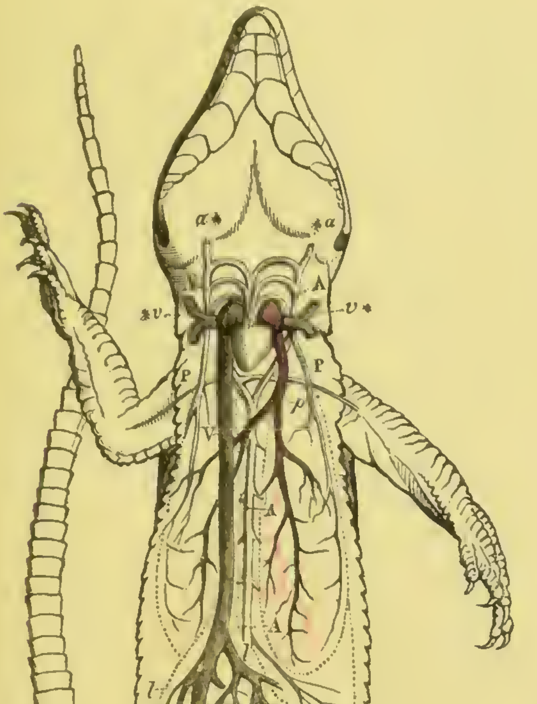
[*] The auricle of the Batrachia was generally described as single until the discovery of the left or pulmonary auricle in the Frog and Toad by Dr. John Davy. Mr. Owen has shewn this to be the case also in the Newt and Protean Reptiles; Zool. Trans, 1834, p. 213. See also Martin St. Ange's Plate of the Circulation, and M. Weber, Beitr. zur Anat. und Physiol. Bonn, 1832.

[*] Leçons, vol. iv. p. 221.

[†] Vergleich. Anatomie, vol. v. p. 231.

Fig. 5.



Lacerta ocellata.

In all Reptiles, however, the descending aorta is formed by the union of two branches, the right and left aortic arches *(figs.* 3, 4, 5, and 6, *A', A)*; the right corresponds with the systemic aorta of birds, and rises from the left ventricular compartment, the left arch joins the right on the back, and leads generally from the right ventricular cavity into the descending aorta. The arteries of the head and upper extremities *(fig.* 3, *a*)*, arising from the right aorta *(A')*, which corresponds with the aorta of birds, and is connected with the left ventricular compartment, are supplied with highly arterialized blood proceeding directly from the lungs. The left arch of the aorta *(A)*, being connected on the other hand with the right ventricular compartment *(H')*, obtains, like the pulmonary artery, venous blood from the right auricle; and consequently the common trunk of the aorta, formed by the union of the right and left aortic arches, must carry to the posterior parts of the body a mixture of arterial and venous blood.* It may be remarked, however, that in the Turtle and some Lizards the left aortic arch does not join the right upon the back until after it (the left) has given off the great cœliac or rather visceral artery, which supplies the whole of the alimentary canal and digestive organs with venous blood *(fig.* 4, *I)*. The left aorta is thus much diminished in size before it sends its comparatively small communicating branch to the right.† From this disposition of the parts, it is obvious that in these animals the abdominal viscera must receive the greater part of the venous blood brought from the right side of the heart by the left aortic arch, while the right aortic arch which gives the carotid, brachial, vertebral, intercostal, and other arteries must carry to the parts it supplies in the first part of its course nearly pure arterial blood, and, after it is joined by the left, blood which contains a small proportion only of the dark or venous kind. In the Turtle, some Lizards and Serpents again, the arterial and venous blood must be mixed in the ventricular cavity though partially divided; the two streams of blood propelled into the aortic and pulmonary vessels must therefore be nearly of the same kind, and thus a part only of the blood which is sent to the lungs is made to undergo a respiratory change. In some of the Chelonia, the existence of ductus arteriosi, leading from the pulmonary artery on each side into the arch of the aorta, insures a still more complete mixture of the arterial and venous blood.‡

In most of the adult Batrachia the ventricle *(fig.* 6, *H)*, being single and giving rise to one arterial trunk only *(A)*, the pulmonary arteries *(P', P)* derive their blood from the great systemic aortic trunk of which they are branches; one coming off from each of the aortic arches which unite to form the descending aorta. The venous blood returning from the system (*V v**) to the right auricle, is mixed in the common cavity of the ventricle with the arterial blood returning to the left auricle by the pulmonary veins (*p*), and this mixed blood being propelled into the aortic bulb is distributed in part to the system and in part to the lungs. In these animals then, only a small quantity of a mixed blood is exposed to the action of the air in the lungs, which, from the simplicity of their structure, offer only a con-

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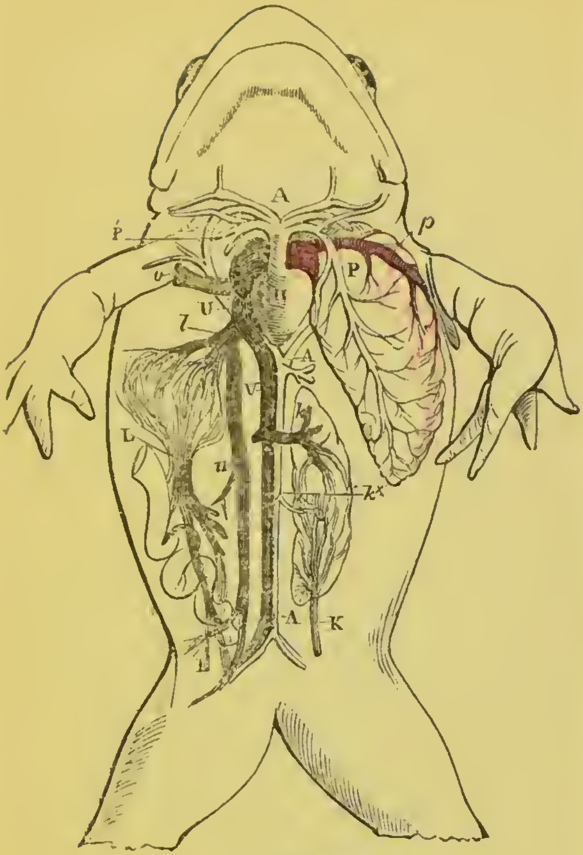
* In the Crocodile, the left branch coming from the right ventricle is small and very short.

† See Bojanus' beautiful Anat. Monography of the Tortoise.

‡ In this respect, as well as in the mode of origin of the left aortic arch, the Tortoise and Turtle differ from one another.

Fig. 6.

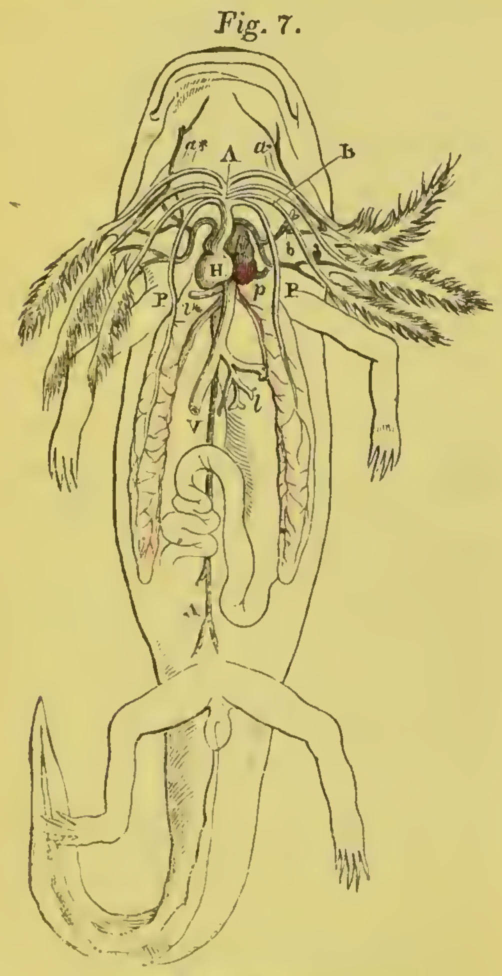


Frog.

fined surface for the distribution of the pulmonary capillary vessels.

In the aquatic Reptiles having gills, such as the larvæ of the Frogs and Salamanders in their transitory conditions, and the Protean animals, which are very similar to them, but do not undergo, so far as is known, any further metamorphoses, the branchial organs are formed by an extension or minute subdivision of branches of the aortic trunk, supported upon the arches of the hyoid bones. In all of these Reptiles, the ventricle consists of a single cavity (*fig.* 7, *H*), which propels its blood into the bulb or commencement of the aortic trunk (*A*). The aortic trunk divides into two branches, each of which subdivides again into three or four vessels upon each side of the neck. These vessels (*B*), passing round the gullet or upper part of the alimentary canal in the form of lateral arches, unite again together behind, to form the descending aorta. The branchial apparatus of the animals now under consideration is formed entirely upon these lateral arches of the aortic trunk. In the larva of the Salamanders, in the Proteus, Axolotl, Menobranchus, and Siren,* the small branches of each gill are formed by the minute subdivision of a loop of vessel prolonged from the outer part of three of the arches on each side into leafed processes of the cuticular system attached to the hyoid arches (*B*, *b*).

Fig. 7.



Proteus Mexicanus (Axolotl).

The larva of the Frog has, in the earliest stage of its existence, gills of the same kind as those just described; but in its more advanced condition these external gills disappear, and the larva of the frog breathes by internal gills more resembling those of fishes than the external branchiæ of the Newt or Proteus. The gills of the tadpole of the Frog are covered by the skin, and consist of a great number of small leaflets, receiving the minutely subdivided loops of vessel given off for some way along each of the four vascular arches as they pass round the neck along the cartilaginous hoops of the hyoid bone. The vascular arches are double in that part of their course where they are connected with the gill, the blood being transmitted from one branch to the other in passing through the leaflets of the gill.

In the larvæ of the Batrachia, from a very early period of their existence, as well as in the Protean Reptiles, there are lungs which seem to be used as adjuvant respiratory organs, for they are generally filled by the animal with air from time to time. These lungs, more or less perfectly developed in different kinds of Protean Reptiles, and at different stages of the existence of the Batrachian larvæ, all receive a pulmonary vessel from the vascular arch of the aorta which is nearest the heart, whether this arch is connected with a branchial apparatus or not.

In all these animals the anatomical relations and the mode of development of the blood-vessels of the gills proves distinctly their returning vessels to be, as much as those which conduct the blood into them, branches of the arterial system; but the lungs on the other hand, however rudimentary, are almost always furnished with proper pulmonary veins which lead to the auricle of the heart.

The following is the course which the blood takes in this interesting class of animals. The heart (*h*, *H*) receives the whole venous blood of the body by the right auricle, and a small quantity of arterial blood from the lungs by the left. These two kinds of blood, mixed together in the common ventricle, proceed from thence into the aortic bulb and its branches (*A*, *B*, *b*). In the larva of the Salamander and Protean Reptiles, a part of the blood is sent by pulmonary vessels to the lungs, from which it is returned by the pulmonary veins to the heart; a part passes directly round the arches, and gains the descending aorta; the greatest quantity passes out into the gills, and after being arterialized returns to be mixed with that in the aorta, so that a mixed blood must permeate all the vessels of the systemic circulation. In the Siren, according to Cuvier and Owen, the whole blood goes at once to the gills, from the want of any communicating twigs across the root of these organs. It is interesting to remark that the arteries of the head and upper extremities (*a*) are not given off by the aortic arches until after they are joined by the returning branchial vessels, a disposition which is in some respect similar to what we find in higher Reptiles, and which seems to have for its object the supply of a more pure arterial blood to the cerebral organ.

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* We omit the consideration of the Amphiuma, Menopoma, and Cœcilia.

In the larva of the Frog, the course of the blood is very similar to that of Fishes. The whole of the venous blood propelled through the heart is sent into the gills, and is made to pass through them before reaching any other part. From the posterior parts of the first arches are given off the vessels of the head, the second form the right and left roots of the descending aorta, and the fourth are continued upon the lungs in the form of a pulmonary artery. There is however also in the larva of the Frog a short anastomosis between the outgoing and returning artery of each of the gills, which allows of a direct passage of some blood round the arches of the aorta.

In the Protean Reptiles and larva of the Batrachia a greater quantity of blood is sent to the respiratory organ than occurs in the adult Frog or Salamander.

Portal circulation in Reptiles.—In the class of Reptiles there are two lesser venous circulations besides those already described; the one, similar to the portal circulation of warm-blooded animals, belongs to the liver; the other, which does not appear to occur either in Birds or Mammalia, belongs to the kidneys. According to Jacobson, who was the first to point out the existence of veins carrying blood to the kidneys in the Amphibia, and the later researches of Nicolai and others, there are two principal vessels which carry back blood from the posterior parts of the body, viz. the anterior abdominal, and the inferior renal veins. These two vessels are formed by the union of the iliac, caudal, posterior cutaneous, pelvic, visceral, abdominal, and umbilical veins; and in most Reptiles, excepting the Ophidia, the renal and portal vessels proceeding from the posterior parts of the body arise together. In some Reptiles the whole of the blood returning from the posterior parts of the body is divided between the portal veins of the liver, and the venæ advehentes of the kidney; in others a part is also sent into the abdominal vena cava. The inferior renal or advehent veins of the kidneys (*figs.* 5, 6, and 7, *K*) carry venous blood to these organs, and distribute it minutely through their substance. It is removed from thence and returned into the great circulation by the revehent or superior renal veins (*k*) which lead into the vena cava.* The anterior abdominal vein (*fig.* 5, *u*) is the same to which Bojanus has given the name of umbilical in the Tortoise, in which class of animals it is of very large dimensions, and receives not only the venous blood from the posterior extremities and shell, but also some from the anterior extremities. The persistence of those umbilical veins which proceed from the large urinary bladder in many of the adult reptiles is a fact of some interest, because it points out a resemblance between the permanent distribution of the vessels in these reptiles and the fœtal condition which we find in the higher animals, and likens the bladder of the scaly Reptiles, as well as of the Batrachia in which during fœtal life no allantoid membrane is ever formed, rather to an allantoid receptacle than to a proper urinary bladder.

Fishes.—In fishes there is no vestige of a pulmonary organ, and the respiration is wholly effected by means of the gills. The branchial apparatus of fishes is internal or covered, like that of the larva of the frog; it is placed on the cervical part of the alimentary canal, and is formed by the fine subdivisions of aortic arches (*fig.* 8, *A*, *B*, *b*), which are prolonged into the fringed or leafy processes of the hyoid branchial arches. The respiratory organ is thus placed in this class in the course of the arterial circulation. The venous blood from the body generally, and from the liver, enters the single auricle (*h*) through the great sinus (*V*), and is wholly propelled into the arterial bulb by (*A*) the single ventricular cavity (*H*). No systemic arteries come from the aortic bulb, but this vessel carries by the arches into which it divides (*B*), the whole of the venous blood into the gills. The number of these arches subdividing and ramifying in the gills varies in different fishes. In a few, as the Lophius, there are only three on each side. In most osseous fishes there are four. In the Skates and Sharks there are five. In the Lampreys there is the greatest number known, namely, six or seven.

The blood, after having undergone arterialization in the gills, is not returned to the heart, but proceeds directly through the branches of the aorta (*fig.* 8*, *b b*, *A*) to different organs. The force of the heart acts therefore through the whole of the capillary system of the gills (*bc*), and continues to propel the arterialized blood

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* It must be remarked that Meckel, who appears to have examined the distribution of the above mentioned vessels with great care, denies entirely the advehent function of the lower veins of the kidneys both in fishes and reptiles, considering all the veins of the kidney as revehent. Vergleich. Anat. B.V. S. 201 and 253.

Fig. 8.

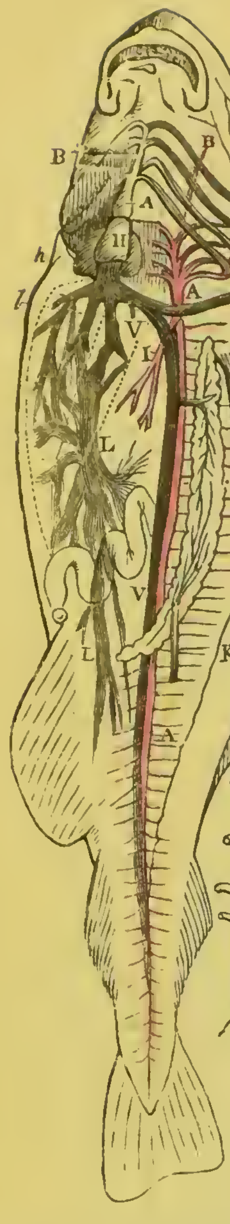
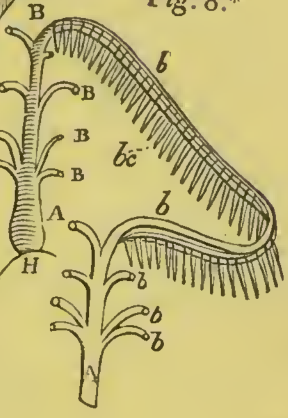


Fig. 8.*



Fish.

through the branches of the aorta (A) in the various parts of the systemic circulation. Dr. Marshall Hall* and J. Müller† have observed a dilated contractile part of the caudal vein in the tail of the Eel, to which Dr. Hall has applied the name of caudal heart, which may assist in promoting the flow of blood in the caudal branches of the vena cava.

The position and anatomical relation of the heart of fishes with the bloodvessels as well as other parts shew that it corresponds to the whole heart of higher animals, and that the arterial vessel which receives the whole of the fish's blood from the ventricle may strictly be considered as the commencement of an aorta entirely destitute of any pulmonary branches. Although there is no distinct right ventricle to propel the blood to a pulmonary organ, and the whole of the blood issuing from the heart is sent directly to the gills, there is not on this account any sufficient reason for considering, as some have done, the heart of the fish as corresponding to the pulmonary or right cavities of the heart in warm-blooded animals, for we have seen that in some of the reptiles when they have gills, the blood is driven into these organs through the aorta or systemic trunk. The branchial arteries in fishes, as in reptiles, are therefore branches of the great aortic trunk, and the returning vessels on the posterior side of the arches, or branchial veins as they are called, are as much of an arterial nature both in their structure and relations as the anterior vessels or branchial arteries are. When these returning vessels unite together on the back to form the descending aorta, it is not necessary therefore to suppose them to undergo a change from the venous to the arterial structure. So far then as general structure and relative position are concerned, the heart of the fish corresponds to the whole heart of warm-blooded animals, and not to one or other set of its cavities. Nor does the contemplation of its function or uses in the circulation induce us to modify this view, for it is manifest that the heart of the fish, as it serves to propel the blood through the gills into the vessels of the system, and as the branchial vessels may be considered as belonging to the aortic system, acts at once as a branchial and a systemic heart.*

We have abstained from entering at this place into the detail of those remarkable changes formerly alluded to, which the circulatory and respiratory systems and the systemic and branchial or pulmonary circulations undergo during the development of the young of animals, although these afford the most direct proofs of the justness of the view now taken. Under the head of Ovum we shall have a more fitting opportunity of explaining these fully. Suffice it for the present to say that the heart of the highest warm-blooded animals passes, during the progress of its development at different periods or stages, through the same general outline of various forms which that organ retains permanently in the adults of fishes or different reptiles; and that the aortic arches and a semblance of a branchial apparatus connected with them is not confined to those animals which necessarily employ gills for a time as respiratory organs, but are to be found also in the fœtus of the scaly reptiles, birds, and mammalia in the early stages of their existence. The ductus arteriosus, double in birds and single in mammalia, is, we may remark, the last of those transitory structures which remains in the fœtus.

Portal circulation of fishes.—In fishes, as in reptiles, both the liver and kidneys have venous blood distributed to them by the subdivision within these organs of veins (L & K) from the abdominal viscera and posterior parts of the body. The vena portæ of the liver consists generally of veins from the stomach, intestinal canal, spleen, pancreas, and sometimes from the genital organs, swimming bladder, and tail. There is, however, considerable variety in regard to the distribution of the posterior abdominal veins in fishes; and comparative anatomists do not appear as yet to have connected these varieties with any general view of their uses. In the Gadus the venous blood from the tail and middle of the abdomen goes to the kidneys only by venæ advehentes. In the Silurus the blood of the posterior parts of the body is carried to both the kidneys and liver; and in the carp, pike, and perch, to the kidneys, liver, and vena cava at once. The blood from the testicle, ovary, swimming bladder, and kidneys, most frequently goes to the vena cava.*

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* Essay on the Circulation of the Blood, p. 170. Lond. 1831.

† Handbuch der Physiol. vol. i.

* Blainville, Sur la Degradation du Cœur, &c. Bull. de la Soc. Philomathique, 1818-19, p. 148.

Course of the blood in Invertebrate Animals.—In investigating the course of the blood in animals destitute of a vertebral column and cerebro-spinal nervous system, we are no longer guided by any such analogies of form, position, and use, as those just attempted to be traced in the circulatory organs of the *Vertebrata;* for each class of Invertebrate animals, as Mollusca, Articulata, and Zoophyta, and even their subordinate orders, differ so widely from one another in their organization, that we are at a loss to discover any general plan or type to which their circulatory organs may be referred.

In all of the Invertebrate animals in which there is a regular progressive motion of the nutritive fluids, there exists also a central contractile organ to which the name of heart is applied, from its functional rather than structural analogy to the central propelling organ of the circulation in Vertebrate animals; and in many of them, the outgoing and returning vessels in which the circulation is performed may be distinguished into arteries and veins, by a difference of structure as well as of office. From the same kind of analogy, the name of auricle is given to the weaker part of the heart of Invertebrate animals, which serves to receive the returning blood from the veins, when such a cavity exists, and we call ventricle the stronger and more muscular part which propels the blood into the arteries. The general form of these parts, however, and their position relatively to the other systems, render it extremely difficult, if not altogether impossible, to trace any strict anatomical correspondence between the heart and bloodvessels of Vertebrate and Invertebrate animals. In the Invertebrate animals, the heart and principal artery are generally placed on the upper part of the body, above the alimentary canal and largest portions of the nervous system; while in all Vertebrate animals the order is reversed, the brain and spinal marrow being above, the heart below the alimentary canal.

In the *Invertebrata,* as in the higher animals, the respiratory change of the blood is the most important function to which its course or circulation bears a constant relation. In the *Vertebrata* the blood flows from the heart to the respiratory organ, while in the Invertebrata the blood very generally arrives at the heart after having passed through the respiratory organ, and is propelled from the heart into the systemic circulation: the vessels, therefore, in which respiration is effected in the lower animals may be considered as belonging in general to the venous circulation only, while in the higher classes of animals, arteries alone, or arteries and veins together, conduct the blood through the respiratory organ. Another remarkable difference between the circulation of the nutritive fluids in Vertebrated animals and that in the Invertebrate classes consists in this, that in the first the digested food or chyle and the lymph are taken up by a system of vessels distinct from those circulating blood, and are poured into the venous circulation at one or more determinate places; while in the latter animals, the bloodvessels, so far at least as we yet know, perform the office of lacteal and lymphatic absorbent vessels as well as of circulatory organs. In the Invertebrate animals also, there is no vena portæ, as in the Vertebrata, and the liver is supplied with blood only by a hepatic artery.

In investigating the structure of the circulatory organs in different classes of Invertebrate animals, we at once perceive that no accurate correspondence can be traced between the varieties of their forms and the places assigned to the animals in a Zoological arrangement; for we find among the Mollusca some tribes having a highly developed and complicated circulatory apparatus, and others with heart and bloodvessels comparatively simply organized. The same discrepancy occurs among the Crustacea, Annelida, and Insects; and among the Entozoa and some other tribes of Zoophytes, while some possess a simple circulatory apparatus, in others we are not able to discover any vestige of a vascular system.

There is a considerable number of the lower animals in which no vascular system has yet been discovered, and in which the nutritious juices are supposed to pass from the alimentary cavity by interstitial transudation through all the parts of their bodies. The circulation has, however, been recently shewn to exist in animals formerly believed to be without it, and the farther progress of Comparative Anatomy may diminish still more the number of animals believed to be destitute of circulating organs: in the present state of our knowledge, it is therefore as difficult to say with certainty in what animals this function is deficient, as it is to fix in which it is of the most simple or most complicated kind.

Mollusca.—The greater number of the Mollusca live in water and breathe by means of gills, but many aquatic Mollusca, possessing a branchial apparatus, appear to have their blood aerated in other parts of the body also. There is a strong muscular heart in all the animals belonging to this class, which when single is always systemic, (*figs.* 9, 10, and 11, *H.*) In the Cephalopoda, besides the aortic or systemic heart, which has only one cavity or ventricle, each vessel (*fig.* 9, *B*) leading to

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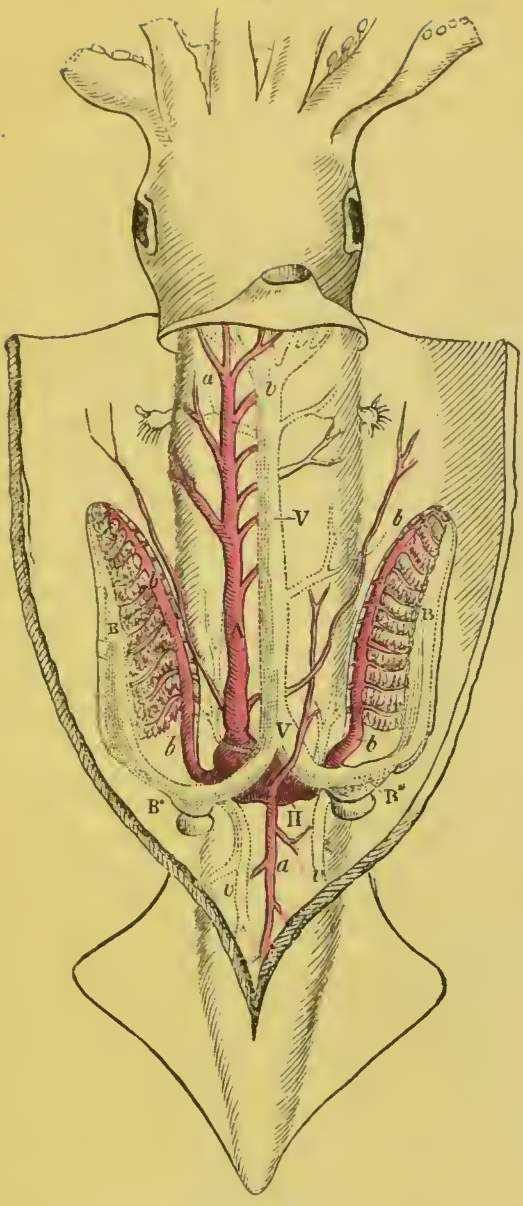
* See the papers of Jacobson and Nicolai already referred to, and the extended Researches of Rathke, Meckel's Archiv, 1826, and Annal. des Sciences Nat. tom. ix.

Fig. 9.

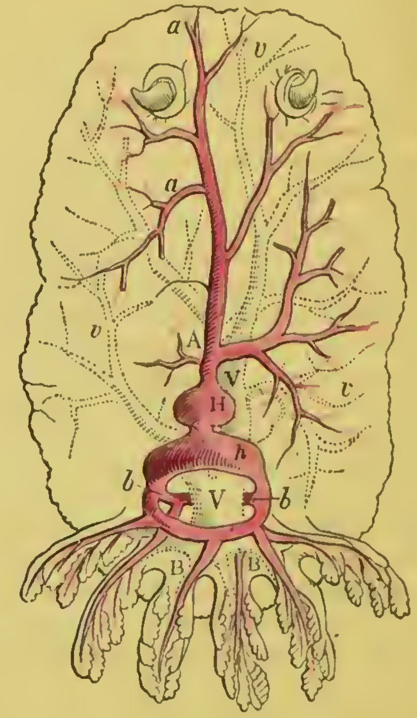


Cuttle-fish.

the gills has a dilated contractile portion (B^*), which dilatations may be considered as branchial hearts, so that there are three separate contractile portions of the circulatory system. In the Gasteropoda and Pteropoda, there is only one heart. This organ is strong and muscular, provided with valves, and consisting of an auricular and a ventricular cavity (*figs.* 10 and 11, *h*, *H*). In the Testaceous Acephala, the heart is nearly of the same structure as in the orders just mentioned, but less fully developed. In most of them, as also in the Gasteropodous Mollusca, the rectum passes through the ventricle. The auricle is occasionally double. The Brachiopoda have two aortic hearts, but of a very simple structure, not being divided into auricular and ventricular portions. The naked Acephala, such as the Ascidiæ, have the simplest heart of all the Mollusca, consisting of a thin membranous ventricle apparently without valves.

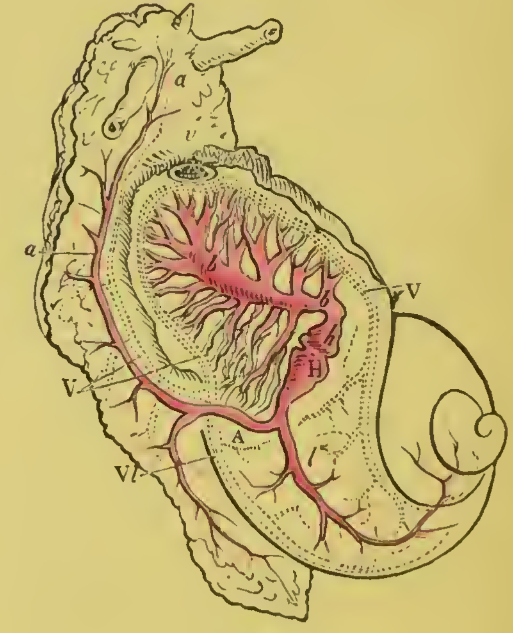
In all these animals, the course of the blood is generally considered to be the following: Arterial blood only passes through the systemic or aortic heart (or hearts where this organ is double), and is carried to the system by the branches of the systemic arteries (*A*, *a*). The altered blood, returning in the veins of the system, is collected into one or more trunks (*V*), and carried in the subdivided branches of these (*fig.* 10, *fig.* 11, *B*) to the respiratory organ, which consists of branchial plates or fringes in the greater number, but in some of the Gasteropoda, as in the Garden-Snail, of pulmonary sacs. In most cases, the whole of the blood returning from the system passes through the respiratory organ. In others, especially in some Bivalves, the vena cava or systemic veins send branches directly to the auricle as well as to the gills.

Fig. 10.



Doris.

Fig. 11.



Helix.

In the compound Ascidiæ, Mr. Lister* has recently discovered one of the most remarkable modifications of the circulation with which we are acquainted. Mr. Lister finds that the different Ascidiæ of a branched animal are not only connected together by the polypiferous stem, but have a common circulation. In each individual there is a heart consisting of one cavity only, and pulsating about thirty or forty times in a minute. In the common stem, the motion of the globules of the blood indicates distinctly two currents running in opposite directions. One of the currents enters the Ascidia by its peduncle and proceeds directly to the heart; the blood issuing from the heart is propelled into the gills as well as the system at once, and upon its return from thence the returning current proceeds out of the animal by its peduncle again into the common stem, whence it goes to circulate through another of the ascidiæ attached to the stem. The directions of the currents appeared to be reversed every two minutes or less. According to Mr. Lister, when one of the ascidiæ is separated from the common stem, its circulation goes on in an independent manner; the blood returning from the body being conducted into the heart, but the alternation of the directions still continues,—a circumstance which points out an important difference between the compound and the simple ascidiæ, in which last the circulating fluid is generally believed to pass from the gills into the heart, and to hold continually the same direction.

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* Philos. Trans. 1834, p. 378.

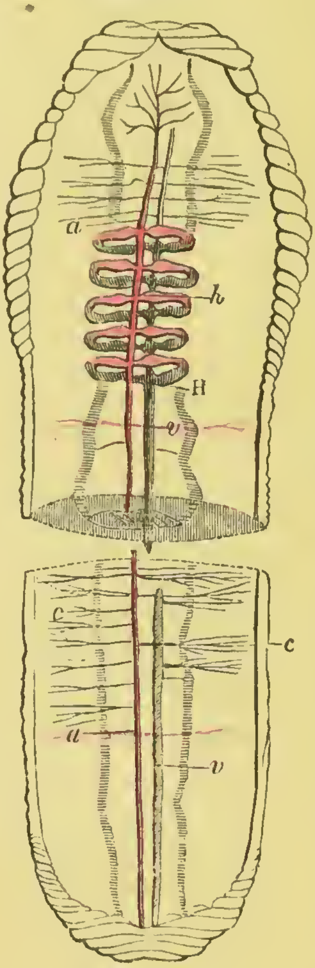
Articulata. — In this class of animals, varied as the forms of the circulatory organs appear, the position of their principal parts is much more constant than in the Molluscous animals. In some, as the Decapodous Crustacea, there is a short and thick muscular heart connected with the systemic arteries. In others, the contractile part of the vascular system is much more like a dilated artery than a circumscribed heart, as occurs in some other Crustacea, spiders, and insects; and in the Annelida the greater part of the large vessels seem to be endowed with a contractile power by which they propel the blood.

Annelida.—Although the Annelida form the highest division of the class Articulata in the arrangement of Cuvier, their circulatory organs may for the most part be regarded as more simple than those of most of the others. The circulation is best known in the Naides, the Leech, Earthworm, and Sandworm. In all of these, the blood, which is generally red, moves gradually forwards in the vessels situated on the upper surface of the animal, and backwards in the vessels placed below or on the abdominal side. There are also numerous cross vessels which transmit the blood from one side to another, or from above downwards, or from below upwards, in each of the compartments or joints of the animal. The upper vessels, being generally the most contractile, are considered as the arteries; the lower vessels as veins.*

The organs of circulation appear to be simplest in the Naides. In these animals, the contractile part or heart is represented by an artery above. This vessel turns round at the head into the vein which is below. The artery sends its blood partly into the gills, placed along the whole length of the body, from which it again receives the returning blood, and by numerous lateral branches, which may be regarded as the only capillary vessels, it sends blood across the body of the animal into the vein. The motion of the blood appears to be partly progressive and partly oscillatory.

Lumbricus. — In the common earthworm, there are two principal vessels, the one (*fig.* 12, *a*,) placed above and the other (*v*) below, and extending the whole length of the body; these two principal vessels communicate together by very numerous small cross branches (*c*), and, in the neighbourhood of the ovaries, by from five to eight very remarkable necklace-shaped or moniliform vessels (*h*, *H*). At the place of junction of these moniliform vessels with the lower longitudinal one, there are small dilatations of that vessel, which are believed to aid in propelling the blood by their contractions. There are also three other longitudinal vessels, much smaller than the principal or median ones, which join with the cross anastomosing twigs. The upper principal vessel pulsates in an undulatory manner, the contraction taking place first at the posterior part, and proceeding gradually forwards. In these animals, however, the course of the blood does not appear to be very well known. It is believed to be from behind forwards in the upper vessel and from before backwards in the lower, but there must be also lateral motion. Both the upper and lower vessels are said to give off pulmonary branches.

Fig. 12.



Lumbricus.

Arenicola.—In the sandworms also, besides the principal upper and lower vessels, there are two smaller ones, placed one on each side of the abdominal nervous cord, and two others upon the intestine; between these there is a very minute net-work of smaller branches. The branchial arteries are derived from the upper longitudinal vessel, the branchial veins lead into the lower. The greater part of the blood proceeds from the upper vessel into the gills by the branchial arteries; by the branchial veins it gains the lower vessel. This vessel may be regarded as the systemic artery, and sends the arterial blood, by the numerous anastomosing branches, upwards across the intestine, and through the other parts into the upper vessel. The upper vessel communicates also with the lower anteriorly by the lateral dilatations named auricles, which are supposed to furnish some blood to the upper vessel. A part of the blood at the anterior extremity of the lower vessel is said to be propelled into the two subordinate vessels placed along the sides of the nervous cord. In this course which the blood is stated to follow, it does not appear to be known whether its motion is of a regular progressive kind or only undulatory.

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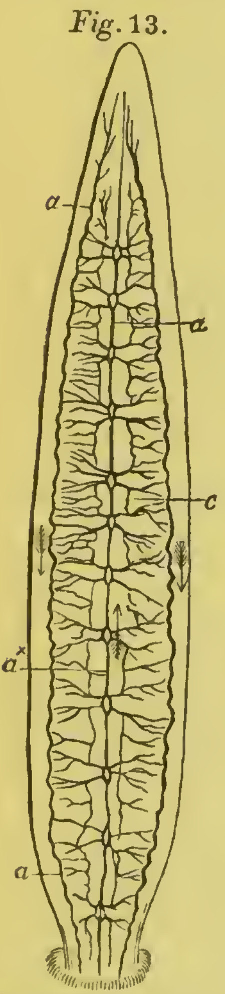
* See Cyclo. Anat. art. Annelida, p. 169.

Leech.—In the leech the principal and most highly contractile longitudinal vessels are placed one on each side (*fig.* 13, *a, a*), and there are also two lesser longitudinal vessels, one superior and the other inferior (*a**), all which communicate freely together by small cross branches along the whole body (*c*). It is remarkable that the lower median vessel (*a**) incloses the ganglionic nervous cord, so as to bathe it with blood. Both pulmonary arteries and veins are branches of the lateral vessels; a capillary network between them distributing the blood minutely over the pulmonary sacs or vesicles. The pulmonary veins form very remarkable dilated and coiled portions, which seem to be endowed with a high degree of contractility. According to J. Müller, for a certain number of pulsations, the middle and the lateral vessel of one side contract together, and propel the blood into the lateral vessel on the other side, and then the order is reversed, and the middle vessel acts along with the lateral vessel of the other side, so that one lateral vessel is always dilated while the median and opposite lateral ones are contracted, and vice versa. According to some there is thus only an alternate motion of the blood from one side to the other, while others believe that there is at the same time a gradual progressive motion of the blood forwards in the upper vessel and backwards in the lower one.*

Fig. 13.



Erpobdella or Leech.

The course of the blood in the principal parts of the circulatory organs is nearly the same in the rest of the Articulata, viz. Crustacea, Arachnida, and Insects, as in Annelida. In all of them the central propelling organ, whether in the form of a heart or consisting only of a dilated arterial vessel, such as the dorsal vessel of insects, is situated on the upper surface of the animal, above the alimentary canal, while the returning vessels are situated on the lower surface of the body, on each side of the nervous ganglionic cord. The respiratory circulation, when occurring in a distinct set of vessels, forms a part of the venous system, and the heart, which has no auricle, is systemic or aortic.

Insects.—All perfect Insects, whether inhabitants of air or water, breathe air alone. In these animals there is not a separate and distinct respiratory organ in one part of the body only, but the atmospheric air is carried by minute elastic and tough tubes ramified to an infinite degree of minuteness into every part of their body.

The dorsal vessel of insects forms a long and wide contractile artery, larger in general behind than before, in which the contractions begin at the posterior extremity, and proceed gradually forwards with an undulatory motion. In the greater number of perfect insects, we are not acquainted with any other vessels or passages in the body, through which the blood moves, and this fluid seems in these insects to oscillate backwards and forwards in the dorsal vessel alone. This state of the circulation in insects, according to the ingenious views of Cuvier, is related to the distribution of the respiratory organ over the whole body, in consequence of which the air is brought in contact with the more perfect blood contained in the dorsal vessel, and the nutritious fluids supposed to pervade interstitially the rest of the body. The recent discovery by Carus of a continuous circulation of the blood through arteries and veins in a few of the perfect insects, and more especially in some larvæ, must modify the above views, which, ingenious as they must appear to all, do not account so satisfactorily for the absence of a systemic as for the want of a pulmonary circulation. The circulation of the blood of Insects may be most easily seen in the aquatic larvæ of Neuropterous Insects, as the Agrion, Ephemera, Semblis, and Libellula,* in which it was first discovered.

In these larvæ it may be described generally as follows. The dorsal vessel (*fig.* 14, *H*) is connected anteriorly and posteriorly by several branches with the inferior or returning vessels (*v, v*), which, running along the whole body, receive the blood from the anterior extremity, and carry it into the posterior extremity of the dorsal vessel. The antennæ and first joint of the legs, as well as the fin-shaped caudal processes, receive each a loop of vessel from the abdominal current; and from the motion of the globules in these transparent parts, the circulation can be more easily seen in them than in

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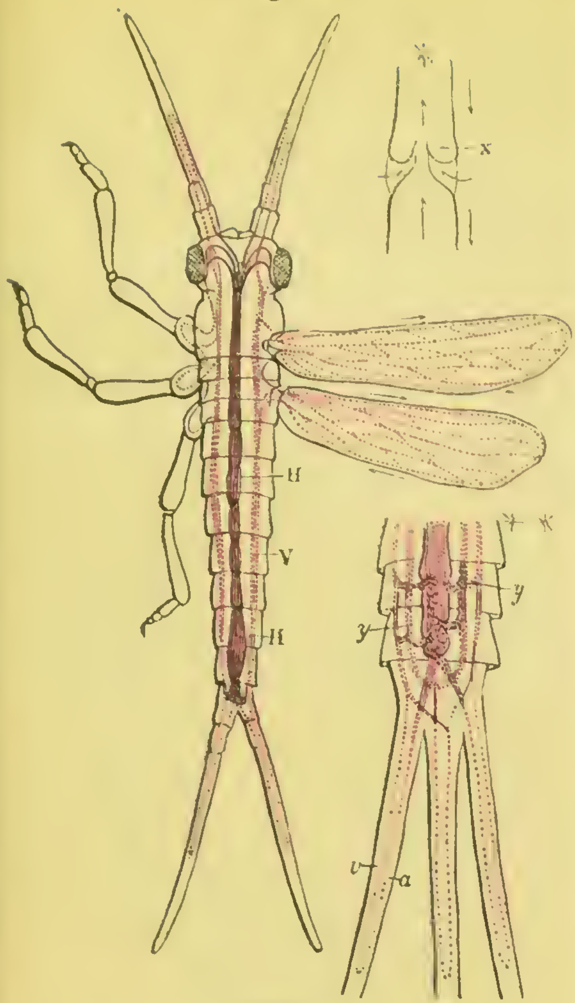
* See a full account of most of the opinions of observers on this subject, as well as original observations by Rudolf Wagner, in the Isis for 1832, p. 643.

* We have ourselves seen the circulation in the larvæ of two Neuropterous Insects.

Fig. 14.



Insects.

any other parts (*fig.* 14**, *a*, *v*). A network of vessels is also distributed over the surface of the imperfectly formed wings. As the metamorphosis from the larval to the perfect state advances, and shortly after the insect leaves the water to assume the aerial condition, the circulation of the blood becomes gradually confined to a more and more circumscribed space. The loops extending into the wings, limbs, caudal processes, and antennæ, become shorter; when the metamorphosis is complete, they become entirely closed, and in general this change is followed by the disappearance of the inferior lateral or returning currents also. These remarkable changes in the circulatory organs at once indicate an interesting relation of their condition to the changes in the mode of life of the insect. In the aquatic state, the caudal and lateral laminæ, antennæ, and wings may be considered as serving the purposes of gills, for the blood is carried to them, and exposed upon their surfaces to the action of the water. The larvæ of the neuropterous insects generally feed largely, but their life during the perfect condition, when the circulation has ceased, is of short duration, and they either take very little food, or live in absolute abstinence. It has been also shewn that the dorsal vessel consists of different compartments, between each of which a valvular apparatus (*fig.* 14*, *x*) prevents the passage of the blood in a retrograde direction. There are lateral openings in the neighbourhood of the valves, by which it would appear that the blood is admitted into the dorsal vessel from cross branches (*fig.* 14**, *y*) passing directly from the lateral streams. It may be mentioned that the larger returning streams of blood, situated on the lower side of the body, are said by Carus and Wagner, we cannot judge with what reason, not to be inclosed within vascular parietes, but to run loose in the texture of the insect. A complete circulation is not, however, confined to the larvæ of insects, having been discovered by Carus and others in some of the perfect insects. Carus saw it in the wings of the Semblis developed for flight. The circulation has also been seen by Carus in the larvæ of Water-beetles, Hydrophilus, and Dytiscus, and by Ehrenberg and Hemprich in the Mantis, so that the circulation has now been discovered in insects belonging to four orders, viz. Coleoptera, Diptera, Orthoptera, and Neuroptera.

Crustacea.—In the Stomapoda, Isopoda, and Branchiopoda, or in the Squill, Oniscus, and Monoculus or Daphnia, the circulation is generally described as being of the same simple kind as that just stated to occur in the larva of insects, with this exception, that the blood is carried to gills for the purpose of undergoing a respiratory change. In most of them the venous blood which is sent to the gills comes directly from the systemic veins. From the description given by Gruithuisen of the circulation in the Daphnia,* it would appear, if his observations are correct, that the venous blood is sent to the heart before going to the gills,—a distribution very dissimilar from that which exists in the rest of the articulated animals. In this animal, Gruithuisen also describes an auricle and ventricle in the heart.

The investigations of Messrs. Audouin and Milne Edwards have pointed out very clearly the structure of the circulatory organs and the course of the blood in the larger Decapodous and some other Crustacea. The aortic heart (*fig.* 15, *H*), consisting of a single ventricular cavity, and situated below the posterior margin of the thoracic shield, gives off six systemic arteries (*A*, *a*), which convey the arterial blood to the various organs of the body and to the liver (l^*). The venous blood, returning thence in the systemic veins (*v*, *v*), is collected on the lower surface of the body into sinuses (*V*, *V*), from which the branchial arteries (*B*) take their origin; the branchial veins (*b*) return the blood which has passed through the gills to the heart.

Arachnida.—In those of the Arachnida in which the respiratory organ consists of tracheæ like that of insects, the circulation has been supposed to be much the same as in these latter animals. The dorsal vessel, however, approaches to the form of a heart posteriorly, being there more dilated at one part than in the rest of its course, and considerable lateral vessels are known to be given off from it upon either side. In others of the spiders, in which the respiratory organ consists of pulmonary cavities admitting air, it is conjectured that the blood is distributed on the surface of the plates

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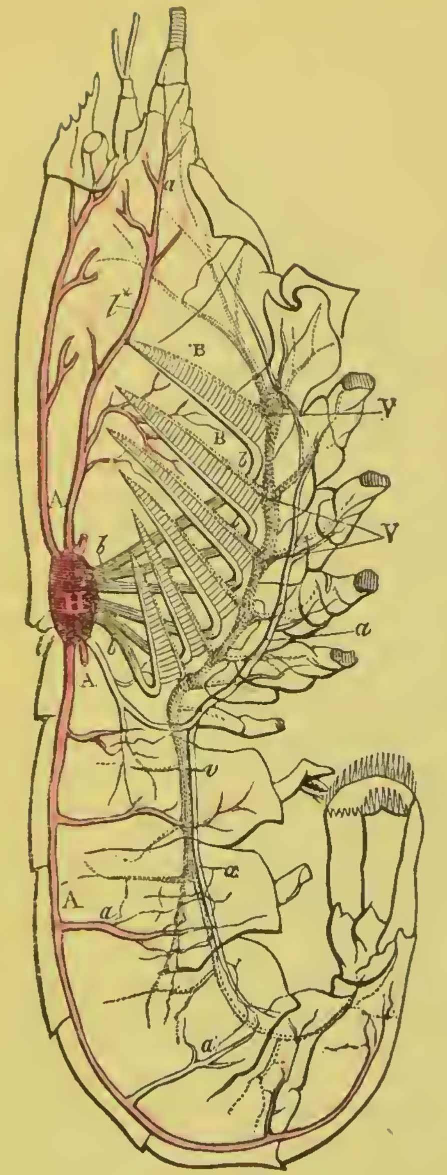
* Nova Acta Nat. Cur. xiv. p. 404.

Fig. 15.



Lobster.

within these sacs, as upon the gills or lungs of other animals, but the exact course of the blood does not appear as yet to have been satisfactorily ascertained in these animals. Audouin* believes it to be essentially the same as in the Crustacea. The long-shaped dorsal vessel or heart gives off arteries to both sides, and receives at one place branches from the gills. The veins form only spaces or sinuses, and not vessels on the abdominal side of the animal. The blood propelled from the artery is passed through the system, returning from which, it is collected into the venous sinuses below, thence it proceeds to the pulmonary organs, and after passing through them, returns to the heart.

Zoophytes.— The general character of the circulation in this class is exceedingly obscure; for while in some of the animals belonging to it, comparative anatomists have not succeeded as yet in pointing out any distinct vascular system; in others, they have been at a loss to determine, among various vascular organs, which of them forms the proper circulatory system corresponding with that of higher animals.

Echinodermata.—Among the Zoophytes the Echinodermata present the most fully developed vascular system with which we are acquainted. According to the observations of Tiedemann and Delle Chiaje, who have investigated the structure of these animals with great success, there are two principal divisions of the vascular system, described by the first of the above-mentioned authors as distinct from one another, by the other as communicating together.

We do not feel inclined to consider, in accordance with the view of these authors, that series of cavities which is employed in locomotion as a part of the nutritive circulatory organs.

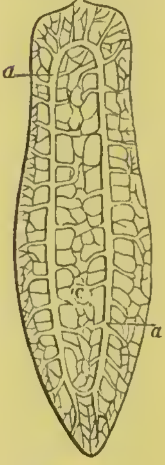
That part of the vascular system of these animals again, which is situated in the neighbourhood of the alimentary canal, very probably corresponds with the circulatory organs which we have been describing in other animals; since arteries and veins can be distinguished in it, and there is good reason to believe that a circulation of fluid takes place through its vessels in all the kinds of Echinodermatous animals.

In the Holothuria, the principal artery or heart is connected with a ring situated round the commencement of the alimentary canal, from which the systemic arteries are given off: the systemic veins send branches to the gills, and the returning vessels from these organs transmit the circulating fluid through one large trunk into the heart.

The intestinal vascular system of the Asterias and Echinus is somewhat similar to that of the Holothuria, consisting of annular vessels, from which arteries and veins are given off, and connected with a dilated contractile canal, considered as a heart.

Planaria.—Next to the Echinodermata in respect of the degree of perfection of their circulatory organs, may be mentioned the Planariæ, in which M. Duges* has pointed out a very remarkable system of vessels which appear to constitute circulatory organs (*fig.* 16, *a*, *a*). For some time previously to the discovery of these vessels, the singularly branched intestinal cavity of the Planaria and some Entozoa was believed to hold the place of organs of circulation, the same cavity in which digestion occurs being believed to carry by its ramifications the nutritious fluids to different parts of the body. But Duges has shewn the existence in them of a system of vascular organs resembling considerably those of the Leech, to which animals the Planaria bears, in other parts of its organization also, a striking analogy. The vascular system of the Planaria consists of three principal longitudinal trunks, two lateral and one dorsal or median, which are all united together by numerous minute anasto-

Fig. 16.



Planaria.

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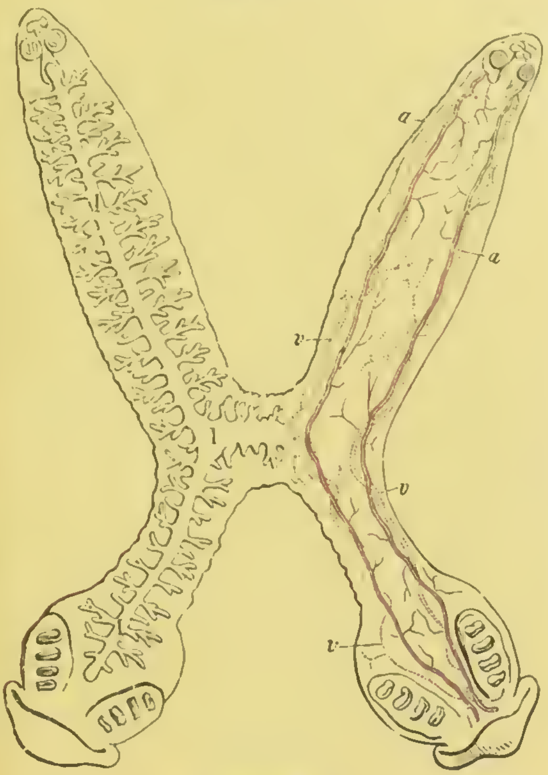
* See Cyclo. Anat. art. Arachnida, p. 206.

* Annal. des Sciences Natur. xv. p. 160.

mosing vessels. The larger parts of the longitudinal vessels have been observed to contract and dilate; but neither a regular progressive circulation, nor a connection of the vascular with any distinct respiratory system has as yet been detected.

Entozoa.—In the Entozoa, organs of circulation somewhat similar to those just mentioned in the Planariæ have been found by Bojanus and Mehlis in the Distoma and Tristoma, and by Nordmann* in those remarkable small Entozoa inhabiting the aqueous chamber of the eyes of some quadrupeds, the Diplostomum, and in the Diplozoon. In the first of these animals, the motion of fluid in the vascular system is exceedingly obscure; but in the Diplozoon (*fig.* 17), Nordmann saw, with a high magnifying power, currents moving in opposite directions in two sets of vessels (a, v) placed on each side of both limbs of the animal. These vessels, termed external and internal, are said to terminate posteriorly in a dilated bag, to which Nordmann gives the name of receptacle of the chyle. The organs of circulation of the Diplozoon differ, therefore, in this respect from those of the Planaria, to which otherwise they bear considerable similarity; for, in the latter animal, the vascular system appears to be entirely closed. According to Nordmann and Ehrenberg no contractions or dilatations of the vessels are visible.

Fig. 17.



Diplozoon.

Acalephæ.—In some of the Medusa tribe, or Acalephæ, there appears to be no distinct circulatory apparatus; and we observe that in these instances, the alimentary cavity is of great extent and is often much ramified on the surface of the animal.

In others there are distinct vessels with a circulation of fluid within them. The distribution of this very simple kind of vascular system was first discovered by Eschscholtz, who has described its form particularly in the Cestum and Beroe. In the latter animal, it is stated that eight arterial vessels and two veins unite with a large annular vessel which surrounds the mouth, and, according to Eschscholtz's* conjecture, another vascular ring, situated at the posterior extremity of the body, forms the means of communication between the arteries and veins in that region. Branches pass from the external or arterial vessels, and from the internal or venous vessels to the fins, which organs seem to serve at once for respiration and for locomotion. Although the motion of a yellowish fluid containing globules has been seen in these vessels, the complete circulation does not appear to have been made out in a satisfactory manner.

Infusoria. — Some kind of circulation is stated to have been observed by Ehrenberg in some of the Infusoria; but this is an observation which, with every confidence in the accuracy of this celebrated microscopic observer, we feel inclined to consider as liable to fallacy, on account of the prevalence of various kinds of ciliary currents in the interior of many of these animals.

Polypi.—We would extend the same remark to the last kind of circulation to which we shall allude, viz. those singular currents of fluid, which were discovered by Cavolini and recently observed by Mr. Lister in some of the Polypiferous Zoophytes. According to the latter observer, in each of the divisions of the stem of the Tubularia indivisa, a current of fluid carrying globules along with it is seen proceeding up one side and down the other. In various Sertulariæ, the direction of the current becomes reversed from time to time. Similar phenomena are to be observed in Campanulariæ and Plumulariæ. The striking analogy which these currents bear to those occurring in the stems of some plants, as Chara and Caulinia, seem to us to bring them under another class of phenomena than those of the vascular circulation of the higher animals. We do not, however, intend to enter upon the consideration of this subject, as it is already fully treated of under the article CILIA.

In concluding our notice of the simpler forms of the circulatory organs, we would remark that one of the great difficulties which retards the acquisition of an accurate knowledge of the function of circulation in the lowest classes of animals, proceeds from our inability to determine, whether currents moving within enclosed spaces in these animals belong to the circulation of their blood and nutritious fluids, or are connected with respiration, locomotion, and other processes of their economy; and this is an obstacle to the progress of the investigation which from its nature we cannot hope soon to see removed.

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* Micographische Beiträge, p. 69. Berlin, 1832.

* System der Acalephen. Berlin, 1829. See the article Acalephæ, p. 43.

In the Planaria, Medusa, some Entozoa, and Polypi, the subdivided or ramified cœca of the alimentary cavity (*fig.* 17, *I*) must obviously contribute to the effect of furnishing a supply of digested matter to the different regions of the body, and of thus rendering a distinct vascular system in them to a certain extent unnecessary. But in these simpler kinds of animals, and even in those of them in which distinct vessels have been discovered, we cannot regard such scattered tubes as the only principal means of distributing the nutritious fluids to the different parts of the body. They may assist in bringing this about; but it is also necessary to suppose the occurrence of an interstitial movement or organic transudation of the fluids, in order to furnish to all the parts the materials for assimilation.

III. PHENOMENA OF THE CIRCULATION AND POWERS MOVING THE BLOOD.

In proceeding to the third division of our subject, viz. the phenomena of the circulation and the powers by which the blood is moved, we would remark, that, however desirable it might appear in a systematic work of this kind to treat of these two subjects under distinct heads, such a separation would have the effect of detaching inconveniently the facts from the legitimate conclusions which may be drawn from them. We shall first state the phenomena and causes of the motion of the blood which belong strictly to the organs of circulation themselves, and afterwards shall treat of various circumstances connected with the other functions by which the circulation is modified. In this view it is our chief object that the facts adduced should bear upon the explanation of the motion of the blood in the human body, but from the nature of the investigation the facts themselves must be drawn chiefly from experiments made upon the lower animals. Of course those experiments and observations which have been made on Mammiferous animals have most value in relation to such a view of the function as that which it is our intention to give. The order which we shall follow is founded on the course which the blood pursues. We shall treat, 1, of the passage of the blood through the heart; 2, of its flow in the arteries; 3, of its passage from the arteries to the veins through the capillaries; and 4, of its flow in the veins.

1. *Flow of the blood through the heart.*—That the muscular contraction of the heart is, in man and in all animals in which this organ exists, the principal source of the power by which the blood is propelled in its course, seems to be satisfactorily proved by the facts, that whenever the action of the heart ceases or is impeded, the whole circulation ceases, and that, when an obstruction prevents the action of the heart from reaching the blood in any of the bloodvessels, the flow of blood ceases almost instantaneously in all the branches proceeding from the obstructed vessel. The constant and regular persistence of the contractions of this muscular organ from the commencement of life to its termination, the early period at which it begins to act in the fœtus, viz. before any regular circulation of blood takes place, and the existence of a heart or some similar contractile organ in all those animals in which a regular circulation of blood or nutritious fluids occurs, are confirmatory of the view suggested by direct observation and experiment. Under the article HEART will be found a detailed account of the structure and functions of this organ; in this place we shall only state, in as few words as we can, what seems to have been best ascertained regarding its action, in so far as this appears to have a reference to the force of impulsion and direction which it communicates to the blood.

The action of the heart may be observed by opening the chest of a living animal, or for a short time in one immediately after death, or best of all in an animal deprived of sense and motion by poison, and in which artificial respiration is maintained; it has also been seen in children born with ectopia cordis, or in persons in whom from accident a part of the heart has been exposed to view. When observed under one or other of these circumstances, the action or contraction of the whole heart is seen to consist of two motions, viz. 1, the contraction or systole of the auricular part, and 2, that of the ventricular part of the organ. The contraction of the auricle immediately precedes that of the ventricle and seems to be continued into it, and the systole of each cavity is immediately followed by its diastole or relaxation.* After the relaxation of the ventricle, there is a period of repose, or a pause in the action of the heart, during which motion seems to be nearly suspended. At the moment when the systole of the ventricle takes place, the heart appears to be diminished in all its dimensions, and exactly at the same instant of time, the apex is seen to be moved towards the sternum, in whatever position the animal is placed. This tilting forwards of the apex gives the heart a pulsation against the ribs that can be felt externally. This pulsation probably depends on the arrangement of the muscular fibres of the heart, as the raising of the apex occurs when the heart is removed from the body and is empty of blood. At the time of the systole the heart is thicker and more conical in its figure than during the diastole; when held in the hand it feels hard, and the ventricles appear to have propelled the whole of the blood out of their interior, as far as one can judge from the great diminution in their size. In the inferior animals, as Reptiles and Fishes, its colour is lighter from the expulsion of the blood. During the relaxation or diastole, the heart appears to fall away from the chest, its parietes become flaccid, and it assumes a flattened form. The pulse in the arteries, which is in truth nothing more than the communication of the impulse of the heart along the blood in these vessels, corresponds, at least in the larger arteries near the heart, very exactly in time with the ventricular systole and the beat on the walls of the chest. The action of the heart is accompanied by two sounds, that can be heard on applying the ear to the cardiac region. The first of these sounds is synchronous with the systole of the ventricles, the second with their diastole; the second follows the first immediately, and is succeeded by an interval of silence. Of the space of time in which a full action of the heart is completed, the systole of the ventricle occupies nearly a third, the systole of the auricle less than a quarter; the dilatation of the ventricle and repose taken together must be effected in the remainder.

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* In some of the lower animals, in the fœtus of the Bird at an early period, and in warm-blooded animals when the action of the heart is weakened, as at the approach of death, the contraction is seen to begin in the venous sinus of the auricle, extend through it to the ventricle, and from one part of the ventricle to another in a gradual manner. In the Batrachia, the contraction begins in the veins, and after passing through the auricle and ventricle, extends into the commencement of the aorta.

The heart, from its structure and action, may justly be considered as a living or self-moving double forcing-pump, which is continually filled at one part and emptied at another. During one-third of the time of a complete action of the heart, the blood in the arteries is impelled onwards by the direct impulse of the ventricles at their systole. During the other two-thirds of the time, while the ventricle is inactive, the communication between its cavity and the great arteries is stopped by the closure of the semilunar valves, and the blood must, herefore, at this time be propelled by the elastic and other forces of the arteries themselves. But the heart continues to receive blood from the veins during a longer time than it gives out any of that fluid, for the auricles offer a resistance to the entrance of blood during only a space of less than a quarter of the time employed in a complete action of the heart, and the blood is continually impelled into the auricles as well as the ventricles during the whole time that these cavities are not contracted, although more blood enters the auricles immediately after their relaxation, and more is propelled into the ventricles just before their contraction than in the rest of the time.

During the systole of the ventricles, while the stream of blood issues from their cavities into the first adjoining parts of the large arteries, the folds of the semilunar valves are laid close to the inner side of these vessels. As soon as the contractile force of the ventricles ceases, the free edges of the semilunar valves are brought towards the middle of the vessel, and applied firmly against one another so as to close the ventriculo-arterial orifices: this is effected by the pressure of the column of blood acted upon by the elastic coats of the arteries, assisted perhaps by the elasticity of the borders of the valves themselves and by the change of position consequent on dilatation of the ventricles.

During the systole of the ventricles, the auriculo-ventricular or tricuspid and mitral valves are closed, so as to prevent in a great measure regurgitation of the blood from the ventricles into the auricles. When the ventricles are in the relaxed state, the valves are opened by the stream of blood flowing from the auricles. The circumstance that the free margins of the mitral and tricuspid valves are bound down to the inner walls of the ventricles by the tendinous cords attached to the fleshy pillars, and that, by the contraction of these pillars, the free margins of the valves must be pulled further down into the ventricle than in the relaxed state, has occasioned to some a difficulty in understanding their action, and led them to suppose that the columnæ carneæ must necessarily be relaxed at the time of the ventricular systole, and that by contracting while the ventricle is in its diastole, the fleshy pillars contribute to open the valves. The direct observation of the contraction of the columnæ carneæ in the heart of an animal taken from the body, and an attentive observation of the structure of these valves, from which it appears that the tendinous cords passing to opposite flaps of the valves frequently come from the same columnæ carneæ or point of attachment in the ventricular paries, sufficiently prove that these fleshy pillars actually contract at the same moment as the rest of the parietes of the ventricles, and that their contraction, besides drawing the free margins of the valves downwards into the ventricles, must also tend to make them approach one another more nearly; and we are therefore entitled to form the conclusion, that, while the tendons serve to fix the valves, the action of the columnæ carneæ is to draw these down so as to allow the blood to pass behind them, and to press them together and close them in the same manner as the semilunar valves of the aorta and pulmonary artery are shut.

The apparently greater facility of the entrance of blood into the heart at one time than at another, has given rise to the opinion entertained by some physiologists that the dilatation of the heart is, like the contraction, accompanied with the production of a new force, which draws the blood from the veins towards the heart. Some who regard muscular elongation as a source of new power have gone so far as to suppose that this force is even greater than that accompanying contraction, but it is manifest that such a view is opposed by every thing we know of muscular action, which leads to the belief that the shortening of muscular fibre ought alone to be considered as an active, and the subsequent elongation as entirely a passive change. Others suppose the ventricles of the heart to dilate in consequence of elasticity, in the same manner as a bag of caoutchouc does after being compressed with some degree of force. Attempts have even been made to measure the extent of the force produced during the dilatation of the ventricles, by endeavouring to ascertain the weight which is displaced by this motion of the heart. We would not wish to be understood to deny the possibility of the heart's exerting some slight force in this way during its dilatation, but it appears very clear that a measurement of the kind referred to must be so difficult as to be almost useless; indeed, it is very probable that some have mistaken the contraction for the dilatation, and we shall afterwards find that the power of suction, exerted by the heart on the blood, as measured by the force with which the veins are emptied, is very small indeed. It is clear that the blood driven on from behind by a propelling power, or flowing through parts which are pressed upon by neighbouring organs, must enter the heart more easily during the relaxation of the parietes of the ventricle than at any other period during the heart's action, so as to give rise to an appearance of suction, but direct experiments make it sufficiently obvious that the force of impulsion from behind is *almost* the sole cause of the entrance of the blood from the trunks of the great veins into the cavities of the heart.

In order to form an estimate of the time in which a given quantity of blood may pass through the heart, or of the time in which the whole quantity of blood contained in the body would take to pass through the heart, several data are required which are not yet furnished by accurate experiments. In the first place, we must know the average quantity of blood contained in the body, and, in the next place, the quantity which is evacuated from the heart at each stroke or systole of the ventricles.

With regard to the first of these points, a number of calculations have been made which vary greatly in their results. Animals have been bled to death by the section of the larger bloodvessels, and the quantity of blood lost has been measured. The quantity of blood lost in this way seems to have varied from 1-10th to 1-30th of the weight of the whole body, and Dr. Moulins, who formed his estimates from experiments of this kind, rated the quantity of blood in the human body at eight or nine lbs. only, or 1-20th of the weight of an average sized man, taken at 150 or 160 lbs. But it is obvious that when one of the larger bloodvessels is opened, from the suddenness of the flow, the animal faints or dies before the whole or even a considerable proportion of the blood has been lost; and it has been ascertained from numerous observations, that when the blood flows more gradually and from small vessels, as occurs in hemorrhages from the nose, stomach, rectum, or uterus, a proportionally much greater quantity of blood may be lost than occasions death in animals experimented upon by the section of the larger arteries or veins. Instances are on record in which from ten to twenty lbs. and even greater quantities of blood have flowed from the human body within twenty-four hours.* We feel inclined on these grounds to coincide with the estimate formed by Haller, that the blood forms about a fifth of the weight of the body, or equals from twenty-five to thirty lbs. in a man of the average weight of 150 lbs. It is obvious that this must vary in different individuals from other circumstances besides a difference of stature. In the young, the quantity of blood is considered to be greatest. Of the whole of the blood contained in the body, it is estimated by Haller, and probably with accuracy, that four parts are contained in the arterial and nine in the venous system.

In endeavouring to estimate the quantity of blood which passes through the heart in a given time, we must find the capacity of the cavities of the heart, we must ascertain whether the cavities on the two sides are of the same size, and, as it is almost impossible to measure the quantity of blood evacuated from the heart at each stroke, we must find to what extent the ventricles empty themselves during their systole. It is obvious that, so long as the circulation is uniform and no local accumulation of blood takes place, the same quantity of blood must pass out of the ventricles into the larger arteries which enters by the veins, and for the same reasons, that the quantity of blood passing through the right and left cavities of the heart must be exactly equal. The circumstance that an equal quantity of blood passes out of the right and left cavities of the heart during their systole does not entitle us to conclude that the capacity of the different auricles and ventricles is the same, because any one of them during its systole may be more or less completely emptied than the rest, and a regurgitation obviously takes place from some of them, so that the whole blood which they contain is not propelled in its onward course. According to some anatomists the auricles are larger in capacity than the ventricles, probably in the proportion of three or two and a half to two, and the auricles are by no means completely emptied during their systole. An opinion has very generally prevailed that the cavities on the right side of the heart are somewhat larger than those on the left. There is no doubt that in making measurements of the relative capacity of the two sides after death, it is most frequently found so; but it is obvious that some have very much overrated the difference, and there is much reason to believe that the greater capacity of the right auricle and ventricle depends in part on the accumulation of blood which generally takes place in most kinds of slow death in the pulmonary arteries, and in part also upon the greater thinness and consequent distensibility of the right ventricle. In men dying suddenly, and in animals killed purposely, in which the pulmonary artery is opened so as to allow of the free egress of the blood from the right side of the heart, the capacity of this ventricle is not greater than that of the left, and the proportions of the capacity of the two sides of the heart usually found after slow death are sometimes reversed when a ligature is placed on the aorta and the pulmonary artery is opened.* Most authors seem to have agreed to follow the estimate of the capacity of the ventricles given by Hales in his Medical Statics. This author estimates the capacity of the left ventricle at 1½ oz. fluid measure, and that of the right at 2 oz. The contemplation of the muscular structure of the left ventricle, and the great diminution in size it undergoes during its systole, would induce us to conclude that it must be completely emptied during the contraction, and that there cannot remain any blood even among the columnæ carneæ. The right ventricle does not appear from the quantity of its muscular substance to be so well suited to be emptied, but its position round the left must assist considerably in the diminution of its size during its systole. In some cases of sudden death in healthy persons, both ventricles have been found completely empty.

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* See Haller's Elementa, and Keill on the An. Econ.

* Sabatier.

The whole of the blood issuing from the ventricles into the first parts of the great arteries is retained within these arteries by the action of the semilunar valves, and it would appear that in the healthy condition the adaptation of these valves is such that very little if any blood regurgitates or flows backwards into the ventricles. At the time that the auricles contract, a very different phenomenon presents itself, for while a certain quantity of the blood from the auricles passes onwards into the ventricles, some is driven back into the orifices of the great veins. This venous regurgitation is particularly evident in the veins connected with the right side of the heart, the orifices of which have no valves or very imperfect ones; and it gives rise to a pulsation in their larger branches, synchronous with the systole of the auricle, as may be seen in most thin persons in the jugular vein at the lower part of the neck. It would appear that upon some occasions, even in the state of health, a certain back stroke from the ventricles also is perceptible in the veins, and Hales was of opinion that some of the blood (half an ounce) from the right ventricle flowed back into the auricle during each systole of the ventricle. It must be apparent that immediately after the auricle has ceased to propel its contents into the ventricle, and just when the systole of the ventricle begins, the column of blood extending from the ventricle into the auricle through the auriculo-ventricular orifice must be continuous, and the pressure of the ventricular systole must thus be transmitted upwards until the valves flap together and close that opening. Accordingly, in some persons in health, a venous pulse, synchronous with the ventricular systole, is occasionally seen or felt in the jugular veins, but this appearance is much more commonly a sign of disease; for the venous pulse which is synchronous with the ventricular systole is much increased when an obstacle presents itself to the free flow of blood through the pulmonary artery, or when from ossification or other morbid alteration, the auriculo-ventricular valves do not close accurately the passage in which they are placed.

We may conclude, from the observations above alluded to, that on an average each of the ventricles of the heart gives out nearly one ounce and a half at each stroke; and we may now state the general calculation of the time that the blood takes to move through the heart, which is generally founded upon the above data. Let us suppose the heart to beat seventy-five times in a minute, which is nearly the average number of pulsations in a healthy man in the prime of life, and assume the quantity of blood in the body at 28 lbs.; and let us suppose that 1½ oz. of blood is expelled from each ventricle into the great arteries connected with them, then 112 oz. or 7 lbs. of blood would pass through each ventricle in a minute, and 28 lbs. in four minutes; or in three minutes, if the quantity of blood passing through the ventricles at each systole be estimated at two ounces, i. e. a quantity of blood equal to that which we conceive to be contained in the whole body, would flow through the heart in the short space of four minutes, and this quantity would run the same course fifteen times in an hour. We must guard against conceiving, on the one hand, that this calculation affords any accurate measure of the quantity of blood which actually passes through the ventricles in a given time, for there are innumerable circumstances which tend to cause this quantity to vary to a considerable extent; and on the other hand, it must at all times be borne in mind that we can, from such calculations, estimate only the velocity of the blood in the heart itself, or the time which a certain quantity of blood takes to pass through its cavities, but that we are not furnished with any measure of the time that the whole of the circulating quantity of blood actually takes to pass through its course, for the length of the courses through which the blood has to pass in different parts of the vascular system varies to such a degree, that in some places, as for example in the bloodvessels of the heart itself, the return to the heart must be effected in less than half the time employed by that which is transmitted to the extremities. On comparing the longest or shortest calculations of this kind made by different authors, we shall find that the time of a circulation is made to vary from six minutes and a half to one minute.

We shall not at present enter upon the consideration of the force with which the blood issues from the left ventricle of the heart, as the experiments by which this force is determined being made upon the arteries, come more suitably to be treated of under the arterial circulation.

2. *Phenomena of the arterial circulation.*— In proceeding to consider the phenomena and causes of the flow of blood through the arterial system, we purpose to treat of, 1st, the velocity; 2d, the force of the blood in the arteries; 3d, the nature of the arterial pulse; 4th, the vital properties of the arteries; and 5th, the influence exerted by this class of bloodvessels on the circulation. We shall find that, in this part of our subject, the difficulty of becoming acquainted with the immense variety of circumstances capable of modifying the flow of the blood, has prevented the explanation of phenomena which are in themselves sufficiently simple and apparent. In our remarks upon the above-mentioned topics, we shall endeavour to

refer the phenomena of the circulation, as far as we can, to hydraulic principles, which, when correctly applied, must form the only sure guide in conducting a physiological inquiry of this nature.

The flow of the blood, as it is expelled from the left ventricle, may be said to be intermittent, for it moves only at the time of the ventricular systole. Farther on in its course, in the larger as well as the middle sized arteries, the flow of blood is remittent, or is more rapid after each beat of the heart, and by the time it arrives at the capillary vessels and commencement of the veins, the velocity is rendered perfectly uniform. The effect, therefore, produced by the arterial tubes is to convert an intermittent, first into a remittent, and afterwards into a uniform force. When an opening is made into one of the larger arteries, the jet of blood which issues is regularly increased in velocity at every systole of the ventricle. In the very small arteries, this acceleration of the stream becomes less perceptible. We know that it has altogether disappeared in the smallest vessels or capillaries, from microscopic observation of the flow of the blood in them, and the uniformity of the velocity of the stream in the veins is clearly shewn in all instances in which a vein is opened, as in the common operation of bleeding from the arm.

Various circumstances shew that in the living body the blood forms an uninterrupted column of fluid in the bloodvessels, and that the whole vascular system is kept in a state of forced distension by the reiterated impulses communicated to the blood by the ventricular contractions. Besides the general fulness of the bloodvessels and their connection with the heart, we may mention as proofs of the distended state of the vascular system, the facts, 1st, that, on opening any of the bloodvessels, the blood issues with greater force at the first moment than afterwards; and 2d, that when we imitate the propulsion of the blood through the arteries and veins by artificial injection of fluids in a dead animal, we observe that the jet from an opened vessel continues to flow for some time after we have ceased to drive the piston of the syringe. The arteries being much stronger than the veins, re-act with greater power than they do against the distending force of the heart. Were the arteries rigid tubes, it is manifest that in a given time just as much blood would pass from their remote extremities into the commencement of the veins, as enters them by the mouth of the aorta; but the arteries must be fuller at one time than another, for the quantity of blood expelled from the ventricle at each systole, must pass suddenly into the first part of the aorta, while an equal quantity of blood, which must necessarily pass from the remote arteries into veins, as it moves uniformly, must employ the whole period of time occupied by a complete action of the heart in its passage; and consequently it is manifest, that the arterial system must be fuller just after than immediately before the contraction of the ventricle. The arteries are distensible and elastic, they yield a little to every successive stroke of the ventricle, and during the diastole they re-act by their elasticity, so as to keep up the flow of blood. We have already said, in speaking of the heart, that the muscular contraction of that organ is the chief, if not the only source of the power propelling the blood. It is only in those arteries which are nearest to the heart, however, that the blood can be said to be propelled by the direct impulse of the ventricle, for in the rest of the arterial system, the progression of the blood is immediately effected by the elastic power of the arteries, called into operation in consequence of their distension by the action of the heart. In the experiments of artificial injection of the bloodvessels in dead animals already mentioned, as long as we continue to drive the piston of the syringe, and to propel fluids through the arteries into the veins, the arteries are kept in a state of forced distension; in consequence of this, the fluid issues from an opened artery with a jet accelerated after each successive stroke of the piston, and continues to flow for some time after the propelling power has ceased to act. The uniformity of the stream of fluid from the veins, which occurs in the same experiment, is a proof that the continued flow of blood in these tubes may, in the living body, be owing to an impulsion from the heart, transmitted by the arteries, and that it is caused by the elasticity of the coats of the vessels themselves.

a. Velocity of the blood in different arteries. The space of the aorta filled up by the blood propelled from the ventricle at each systole, divided by the time occupied in its propulsion, constitutes the velocity of the blood in the first part of the aorta. The diameter of the aperture of the aorta at the ventricle being taken as on an average 1·12 of an inch,* its area would be one square inch, and consequently 1½ oz. which equal 2·45 cubic inches of blood, would occupy a little more than 2·5 inches of the aorta, supposing its size to be for such an extent of a uniform diameter. As it is satisfactorily ascertained by actual measurement, that the blood contained in the smaller vessels is in much greater quantity than that in the larger trunks; or, in other words, as the capacity of the smaller vessels taken together is greater than that of the larger, it will at once be apparent, that the velocity of the blood must diminish in passing from the larger to the smaller vessels. The arterial and venous vessels may in fact be regarded as two hollow cones, curved so as to be joined at their apices to the heart, and at their bases to one another. The veins, being more numerous and wider than the arteries, must be represented by a wider cone. The section of these cones at any place is supposed to give the combined area of the section of the vessels at a corresponding distance from the heart.

The estimates made by different authors of the relative velocity of the blood in the larger and smaller vessels, differ in a great degree, and are exceedingly unsatisfactory. Haller, who fully admitted the greater capacity of the smaller arteries, and allowed that the flow of the blood must therefore, from hydraulic principles, become less rapid in passing from the trunks to their branches,—a proposition which he illustrates by comparing the stream of blood in its passage to a river which enters a lake,—was yet inclined, from the result of his actual observations, to deny that the velocity is much less in the smaller than in the larger arteries. Spallanzani, although admitting more explicitly still than Haller the necessity of such a retardation, seems to have met with the same difficulty in reconciling theory with his attempts to measure the velocity of the blood in the small vessels: and both these authors state, that although the circulation was in general comparatively slow in the web of the frog's foot, still in many instances in this situation, and more frequently in the mesentery, they were unable to detect any difference in the rapidity of the flow of the blood in the larger and smaller arteries.*

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* The aperture of the aorta is somewhat less than one inch in diameter in most persons; we may, however, adopt the above estimate of its size, as the sinus of the aorta is much wider than its aperture.

Hales, again, states as the result of his observations and measurements, that the velocity of the blood in the smallest capillaries of the abdominal muscles of the frog, is so small as one or one and a half inch in a minute; and, from the attempts which we ourselves have made at these measurements, we feel inclined to agree with the statement of this able experimenter, having, upon several occasions, ascertained that in those capillaries which admit only two globules of blood, the velocity is not greater than the hundredth part of an inch in a second; but it seems doubtful whether in all the capillaries the velocity is so small as in those just alluded to, and in the larger capillary vessels of the diameter of six globules, when no unnatural obstruction to the circulation in the limb occurred, independently of the difficulty of fixing the eye upon any globule in such a way as to trace its progress along the vessel, the velocity has always appeared so great as to prevent the possibility of measuring it; and we are at a loss to conceive in what manner Haller made the comparison he speaks of between the velocity in the larger and smaller arteries. By means of the microscope, it is easy to see that the velocity is greater in the small arteries than in the corresponding veins, which are both more numerous and considerably larger than the arteries.

The results of actual observation of the flow of the blood and of the measurement of the relative capacities of different arteries, afford as yet very unsatisfactory data upon which to found an estimate of the relative velocity of the blood in the trunks and branches of the arteries. In the absence of more direct means of calculation, an approximative estimate may be made in another way, viz by comparing the quantity of blood which occupies a known space of the larger vessels with the whole quantity of blood contained in the body.

We have already seen that the whole blood in the body may be estimated at nearly thirty pounds: now, let us suppose the aorta and pulmonary arteries, together with their returning veins, to form a continuous tube of the length of the two courses of the blood, in the systemic and pulmonic circulations, and of the same diameter as these vessels at their point of junction with the heart; a very simple calculation shews us that such a tube is capable of holding only about six pounds and a quarter, or less than a fourth part of the whole blood of the body; or in other words, were the aggregate capacities of the small vessels no more than equal to that of the larger, they would be capable of holding only a fifth of the blood contained in the body.

The velocity of the blood in the commencement of the aorta may be considered as two and a half inches in a second, for this is the space occupied by all the blood which is propelled into the aorta from the left ventricle in that time, and according to the arbitrary modes of estimating the relative capacity of the aorta and its branches here employed, the velocity of the blood in the aortic capillaries generally, might be considered as one-fourth of that in the commencement of the aorta, or nearly half an inch in a second, a result widely different from that obtained by Hales.

Attempts have also been made to estimate the velocity of the flow of blood, by observing the time which certain substances, when introduced into one part of the vascular system, take to pass to another. The most remarkable series of experiments of this nature with which we are acquainted were performed by Hering.* This author states that he has been able to detect prussiate of potassa, which he had introduced into one of the jugular veins of a horse, in the blood drawn from the opposite jugular vein in the space of from twenty to thirty seconds; and he has formed the conclusion from this experiment that the prussiate of potass, in order to gain the jugular vein on the opposite side of the body, had passed in this remarkably short space of time through the whole course of the double circulation: that it was first carried to the heart, then passed through the pulmonary arteries and veins, and returned to the heart, from which it must have been transmitted through the ultimate ramifications of the systemic arteries before being brought back by the veins, in which it was found on the opposite side of the body. Hering states, as the result of other experiments of a similar nature made upon different bloodvessels, that the prussiate of potassa passed from the jugular vein to the saphena vein in twenty seconds; to the masseteric artery, in fifteen to twenty seconds; to the external maxillary artery, in ten to twenty-five seconds; to the metatarsal artery, in twenty to forty seconds.

We consider these curious experiments as important in many points of view, but do not feel inclined to concur in the conclusion deduced from them by their author, that the circulation of the blood, rapid as it may be, takes place in this remarkably short space of time, and we are disposed to suspect that the experiments themselves are liable to several sources of fallacy. The tendency of the prussiate of potass to permeate the textures of the body, more freely than any other substance known, has been proved by many experiments, and it is therefore necessary that Hering's experiments should be performed with some other substances, before they can be regarded as a correct means of estimating the rapidity of the circulation.

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* Haller appears to mean here arteries of considerable size.

* Tiedemann's Zeitschrift, vol. iii. p. 85.

The velocity of the blood is generally believed to be greater in the pulmonic than in the systemic circulation,—an opinion founded chiefly on the supposed less capacity of the vessels belonging to the pulmonary trunks. Actual measurements of the velocity of the blood in the capillaries of the lungs of cold-blooded animals by Hales, Spallanzani, and others, would seem to give support to this view, but it must at the same time be recollected that the course through which the blood passes in the pulmonary or lesser circulation, is considerably shorter upon the whole than that of the systemic or greater,—a circumstance which must diminish to a certain extent the disproportion in the velocity.*

b. Force of the blood in the arteries and force of the heart.—Another interesting inquiry connected with this subject relates to the force with which the blood is impelled in the arteries, and the calculations that have been made of the power of the heart itself, from the observation of the force of the blood in the arteries. The experiments made with a view to discover these forces appear sufficiently simple in their nature; but the calculations founded upon the experiments have differed so widely, as to have furnished a plausible pretext for throwing ridicule on the application of physical laws to the living animal functions.

As the arteries and other vessels are kept distended with blood by the action of the heart, it follows that were they rigid tubes, the force of the heart would, in accordance with the laws of propagation of pressure through fluids, be transmitted without loss through the whole column of blood in the arteries at one and the same moment: but in consequence of their yielding to distension, the force of the heart operates upon the blood only through the elastic reaction of the coats of the arteries.

When an opening is made into one of the larger arteries, the blood issues with force, and spouts to some distance, but the height to which the blood rises when allowed to escape from a simple aperture in an artery varies from many accidental circumstances, and cannot therefore be taken as affording an accurate measure of the force with which the blood moves within the vessels.

Hales seems first to have investigated this force in a more accurate and experimental manner, by observing the weight which the blood in one of the arteries of a living animal is capable of sustaining within a tube adapted to it. He remarked that the blood issuing from a simple aperture in the carotid artery of a horse and directed upwards did not rise above three feet,* but that when the blood was allowed to pass into a long glass tube adapted to the same artery it rose very quickly to a much greater height, as to nearly ten feet in some of the experiments. Hales performed similar experiments on the arterial flow in sheep, oxen, dogs, and other animals, and after observing for each the pressure which the blood in the arteries is usually capable of exerting, he endeavoured to compute the pressure of the blood in the arteries of man, by a comparison of the size of his whole body or heart and bloodvessels with those of the other animals. The pressure of the blood in the aorta of the horse being considered as eleven pounds, Hales estimates in the way above-mentioned the force of the blood in the human aorta at 4 lbs. 6 oz.; seven and a half feet being the height to which he supposed that the blood would rise in a tube connected with the larger arteries of a man.

These experiments of Hales shewed in a very clear manner, that the height to which the blood rises in one of the larger arteries affords us the means of ascertaining directly the amount of pressure which the stream of blood impelled by the heart through the arteries is capable of exerting at any part of the arterial system, or in other words it gives us a measure of the statical force of the heart as it operates through the arterial tubes.†

According to a well-known law of physics, the heart must be pressed upon in every part of its internal surface by the column of blood which it has raised; so that by multiplying the area of the internal surface of the ventricle into the height of the column of blood supported in the tube connected with an artery, we shall ascertain the pressure which acts backwards on the inner surface of the heart. Hales estimates the inner surface of the ventricle of the human heart at fifteen square inches, and multiplying the pressure of a column of blood of seven feet and a half high into the area of the inner surface of the heart: he hence calculates the pressure on the inner surface of the human heart to be nearly 51½ lbs. The pressure on the interior of the horse's heart he estimates at 113 lbs. upon similar principles.

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* In reference to the above calculations, it must also be kept in mind, in the first place, that the estimate of the velocity of the blood in the pulmonic circulation in the frog can scarcely with propriety be applied to man, seeing that in the frog the pulmonary artery is only a branch of the aorta; and, in the second place, that in animals with a double circulation, although the quantity of blood which leaves both sides of the heart at each systole be equal, it does not necessarily follow that the whole blood which circulates through the system should in the same time pass through the lungs.

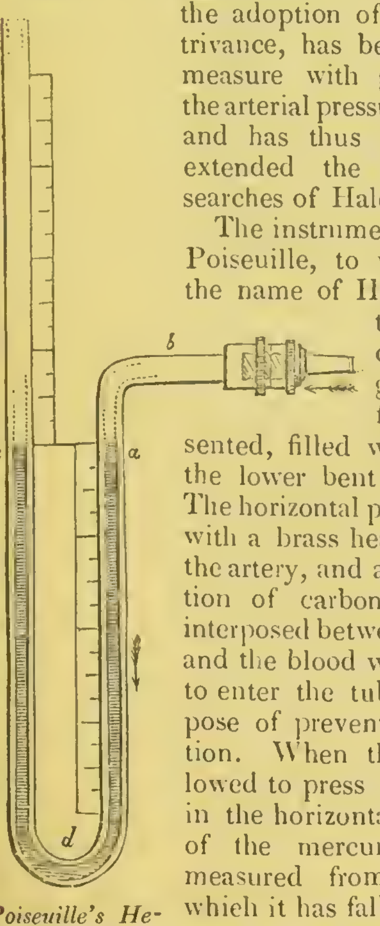
* This experiment we have repeated with Mr. Dick's assistance.

† These experiments, as well as others subsequently performed, demonstrate the importance of confining our researches in an inquiry of this nature to the estimation of the statical force operating in the organs of circulation, as the only useful object of such calculations,—the propriety of which is also sufficiently apparent from the extraordinary results of the attempts to estimate the dynamical power of the heart or the whole force generated in that organ by muscular contraction, by Borelli and Bernouilli, the first of whom calculated this force to equal 180,000, the second 3,000 lbs.

As pressure applied in any direction to a fluid column is equally transmitted through all its parts, and as the blood in the arteries forms continuous columns which all branch off from the aorta, it might *a priori* have been concluded that the force of the blood must be the same in all the arteries of any considerable size. Hales, though he does not state this proposition very explicitly, seems yet to have taken it for granted; for, in estimating the pressure of the heart, he takes into account merely the height of the column without reference to the size of the artery. We shall find this proposition to be satisfactorily proved to be correct by direct experiments subsequently performed.

The experiments of Hales were liable to two principal objections: 1st, that the coagulation of the blood in the long glass tube adapted to the artery must have prevented its free motion; and, 2nd, that the length of the tube, besides giving rise to the necessity of frequently removing it and various other inconveniences, must have occasioned a considerable loss of blood in filling from the arteries of small animals. Both these sources of fallacy have been provided against most successfully by M. Poiseuille,* an ingenious experimenter of Paris, who, by the adoption of a simple contrivance, has been enabled to measure with great accuracy the arterial pressure of the blood, and has thus confirmed and extended the interesting researches of Hales.

Fig. 18.



Poiseuille's Hemadynamometer.

The instrument employed by Poiseuille, to which he gives the name of Hemadynamometer, (*fig.* 18,) consists of a bent glass tube of the form here represented, filled with mercury in the lower bent part (*a*, *d*, *e*). The horizontal part (*b*), provided with a brass head, is fitted into the artery, and a little of a solution of carbonate of soda is interposed between the mercury and the blood which is allowed to enter the tube for the purpose of preventing its coagulation. When the blood is allowed to press upon the fluid in the horizontal limb, the rise of the mercury towards (*c*) measured from the level to which it has fallen towards (*d*) gives the pressure under which the blood moves.

One of the most important facts established by Poiseuille's experiments is, that the pressure of the blood is within certain limits nearly the same in arteries of very different calibre and at different distances from the heart; as proved by the rise of the mercury of the hemadynamometer to nearly an equal height when this instrument was connected with the iliac, carotid, radial, facial, and other arteries in some of the lower animals. It is hence apparent, that, in order to ascertain the whole amount of force with which the blood is propelled in the aorta, or the statical force of the heart itself, it is sufficient to measure by means of the tube the momentum of the blood in any one of the arteries. Poiseuille estimates the force with which the blood is propelled in the commencement of the aorta in man at 4 lbs. 3 oz.,—a result which agrees remarkably with that obtained by Hales.*

Poiseuille, however, considers the pressure backwards within the heart to amount to 13 lbs. only, as he calculates this in a different way from that followed by Hales, viz. by multiplying the pressure of the blood in the aorta into the surface of a plane passed through the base and apex of the left ventricle,—a mode of calculation which it appears that Dr. Hales had not lost sight of; for, at page 21 of the work on Hemastatics, he proposes it as the "means of estimating the force of the blood which the muscular fibres of the ventricle must resist."

Poiseuille estimates the force with which the blood moves in the radial artery of man at four drachms.

Hales had remarked that the blood in the tube connected with an artery rose regularly a little way at each systole of the ventricle, and remained always somewhat higher during the straining of the animal, that is, while the muscles of expiration were in action. These phenomena, known to Haller, were demonstrated experimentally by Magendie, and receive a still more decided confirmation from the experiments of Poiseuille made with the hemadynamometer.†

We would here remark that, it having been shewn by the above-mentioned experiments that the force of the heart is sensibly the same in the trunks and larger branches of the arteries, it is manifest that the angles of ramification and the friction of the blood against the sides of the vessels can give rise to very little if any diminution in the force of the heart transmitted by the elasticity of the arterial parietes. We shall afterwards see that the case is very different in the smaller vessels.

We would also call the attention of the reader to an interesting application of the fact of the complete transmission of pressure through the fluid contained within the bloodvessels in all directions, in the immense force which the blood occasionally appears to exert within an aneurismal tumour; giving rise to its peculiarly hard pulsation on every side, and assisting the ravages by absorption which are frequently the consequence of the larger internal aneurisms. The pressure in an aneurism is obviously to be measured by the extent of its internal surface multiplied into the force with which the blood moves in the part of the artery where it opens into the aneurismal sac.

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* Magendie's Journal, vols. viii. & ix. Breschet's Repert. d'Anat. et de Physiol. 1826.

* The power of the heart has also been calculated from the force supposed necessary to raise the foot of one of the legs thrown across the other in the pulsatory movement which is then seen to occur,—one of the most inaccurate methods that could be adopted.

† See Part IV. of this article.

c. Arterial pulse.—The arterial pulse, or succession of beats felt by the finger placed over an artery, depends upon the impulse of the left ventricle being communicated along the arterial tube and the column of blood which it contains.

When a ligature is put upon an artery, no pulse is felt beyond the place where the artery is obstructed, but it is distinct up to that place. This experiment at once shews the dependence of the pulse on the systole of the ventricle, and establishes that this phenomenon is not dependent on the progressive motion of the blood, since, in that part of the artery placed on the side of the ligature next to the heart in which the pulse is distinct, the blood is at rest. Nor does the pulse appear in ordinary circumstances to depend upon lateral distension of the arteries, for such distension occurs to so small a degree as is quite insufficient to account for the production of the pulse. Arthaud,* a French surgeon, was the first who sustained, in opposition to the opinion prevalent at the time he wrote, the view that the arteries are not laterally dilated at each systole of the heart, and that the pulse is not to be explained by such dilatation. Arthaud shewed that when an artery is laid bare, no perceptible enlargement of its calibre takes place at the time when the heart contracts and the pulse is felt. We have already stated that the arterial system being fuller of blood at one time than another must be dilated to admit the blood propelled into the aorta from the ventricle; and it seems to follow from the observations of Arthaud, which have been ably confirmed by the interesting experiments of the late Dr. Parry,† that the enlargement of the capacity of the arteries is effected principally by their elongation. According to these experimenters, when one of the larger arteries is laid bare, the eye does not distinguish any lateral enlargement corresponding to the systole of the ventricle, and Parry measured with great care the artery at the time of each pulse and between the beats without being able to detect the slightest differences in its size; but though not perceptibly distended laterally, the artery undergoes a certain change of place, for at each systole of the ventricle it is propelled in a direction outwards from the heart, and during the diastole it returns to its former situation. This locomotion of the artery, as it is called, is obviously produced by the distension and elongation of the larger arteries near the heart. A considerable elongation of the arteries may also easily be seen at all sudden incurvations of these vessels. The bend of the curved part is generally increased and projected further outwards during the systole; and we observe that a straight part of an artery, if fixed at its opposite ends, is bent at the time of the pulse in consequence of its elongation. In many persons in a state of health the arteries may be seen to move under the skin, although not exposed. This motion is generally perceived at places where there is a sudden bend of an artery, or where the artery lies upon an unyielding part, as bone, &c., and in some individuals an appearance of dilatation or lateral enlargement even may be perceived in some of the larger arteries. Although these circumstances shew that the pulse is not attributable to a lateral dilatation of arteries, yet it would appear that such an enlargement does occur in a small degree, for it is occasionally perceptible to the eye in the arteries when laid bare; and M. Poiseuille,* by means of a small apparatus, capable of being applied round a part of an artery, has proved distinctly the occurrence of lateral enlargement, and estimated its extent in the larger arteries at 1-11th of their diameter.

The finger laid upon an exposed artery does not feel any pulse, unless the artery be compressed, and when the arteries are in their natural situation covered by the integuments, it is only when they lie upon a hard part, as a bone, and when the sides of the artery are brought nearer to one another by pressure, that the pulse is perceptible. Those instances in which this does not appear to be the case, as well as those in which the dilatation occasionally seems to occur below the integuments, may in like manner depend upon the artery being subjected to pressure of superjacent parts at the place observed. It is also sufficiently obvious that the pulse does not depend upon any active change of the artery itself, or upon any vital contraction and dilatation of the vessels, for the exact appearance of the living pulse may be produced in the arteries of a dead animal by injecting water into the arteries with a syringe, if care be taken to imitate with the strokes of the piston the beats of the left ventricle of the heart. A further proof of this, and an excellent illustration of the nature of the pulse, is obtained from the curious experiment performed by Bichat of connecting the bloodvessels of a living animal with those of a dead one, the result of which is the production of a pulse in the vessels of the dead animal connected with the arteries of the living one. In those instances in which a communication has been established between an artery and a contiguous vein in consequence of a wound, or in what is called Aneurismal Varix, the vein pulsates exactly like an artery.

Many have remarked that the pulse in the arteries of the extremities is a little later than the beat of the heart on the ribs and the pulse in the arteries in the immediate neighbourhood of the heart. This retardation has of late been more distinctly pointed out by Dr. M'Donnell of Belfast,* and by Weber of Leipsig.† It is much more marked in some persons than in others, and is always most perceptible when the circulation is slowest. With a little attention we can thus observe a distinct succession in the occurrence of the beat of the apex of the heart at the ribs, the pulse in the carotid, facial, radial, and posterior tibial arteries, the interval between each of which, though very small, being yet appreciable by the finger. Weber states that the retardation of the pulse in the foot after that of the beat of the heart amounts to not more than one-seventh part of a second. We have ourselves confirmed by experiments on several individuals the most of these facts relating to the later pulse in the more remote arteries. The cause of the retardation is obviously the elasticity and yielding of the arterial parietes; for were the arteries rigid tubes, it is manifest that the impulse of the heart would be felt at one and the same instant of time throughout the whole of the branches; but as these vessels yield to distension, that part of them to which the distending force is immediately applied is first dilated, and this dilatation does not reach immediately the remote parts.

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* Dissert. sur la Dilatation des Artères. Paris, 1770.

† Dr. C. H. Parry's Inquiry into the Nature of the Arterial Pulse. Bath and Lond. 1816. Dr. Chas. Henry Parry's Additional Experiments. Lond. 1819.

* Sur la dilatation des Artères; Magendie's Journ. vol. ix. p. 44; and Breschet's Repert. 1828.

The pulse has been correctly compared to the propagation of an undulation or wave on the surface of water; for the successive impulses of the heart are first given to the column of blood in the commencement of the aorta; this column communicates these impulses to the arterial parietes and tends to distend them. The parietes re-act against this distending force and compress the adjoining part of the column of blood, from which the impulse passes to the next part of the aorta; and so the pulse, gradually passing on from the trunks to the smaller branches, becomes less and less perceptible as the force of the heart is equalized by the elastic resistance of the coats of these vessels.‡

The pulse is still perceptible in very small arteries: Haller§ states that he was unable to perceive any in small arteries of one-sixth of a line in diameter,—an observation which does not, however, prove the flow of the blood to be uniform or without jerks even in vessels of this size, for Spallanzani|| observed pulsations in arteries of this small size; and the microscopic observation of the circulation in transparent parts by Haller himself, Spallanzani, and others, shews that the visible impulse of the heart is communicated to the blood in the smallest of those vessels, which have distinctly the characters of arteries.

The pulse being nothing else than the beats of the heart transmitted through the arteries, the consideration of the variations in force or frequency to which it is subject belongs more properly to the subject of the functions of the heart. In this place we shall only mention the mean of the usual number of pulsations of the arteries in the space of a minute as they occur at different periods of life.

Child before birth	140—150
Newly-born infant	130—140
Child one year old	120
Two years.............	108
Three years	95
Seven years	85
Age of puberty..........	80
Manhood	75
Old age	60—50

d. Vital properties of the arteries.—In the view we have hitherto taken of the arterial circulation we have considered the coats of the arteries as endowed with physical powers only, and we have alluded to no other phenomena of the motion of the blood than those which appear to be connected with their elasticity. We have now to direct our attention to the more strictly vital and contractile powers of the arteries, which constitute them an independent source of force, and to examine how far the operation of such powers may modify the flow of the blood. We shall here discuss more in detail the questions whether the heart is to be regarded as the only source of the power by which the blood is impelled, and the bloodvessels merely as the modifiers or regulators of the force generated by the heart's contraction—or whether the arteries do not, by their own independent power, contribute to the propulsion of the blood.

Physiologists are very much divided in their opinions upon these questions, some regarding the heart as the sole moving power, some supposing the bloodvessels to be the principal, the heart a subordinate cause of motion; and others adopting various modifications of these opposite views. Many who agree in considering the heart's action as insufficient to propel the blood through the smaller bloodvessels into the veins, differ as to the cause of the additional power supposed necessary for the maintenance of the circulation; the larger and middle sized arteries being looked upon by some as highly contractile, and in consequence of this, the agents of propulsion; the capillaries being regarded by others as the most efficient promoters of the flow of the blood within the bloodvessels. We must, for the present, confine our remarks to the first of these, or the opinion that the larger arteries are mainly or in part the agents of the propulsion of the blood.

That the arteries have the power of changing, to a certain extent, the quantity of blood which passes through them, and of thus modifying the circulation by their own independent powers, there can be no doubt, from the occurrence of unequal distributions of blood, or of local de-

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* At the Meeting of the British Scient. Associat. in Dublin.

† De pulsu in omnib. arter. plane non synchronico. Annot. Academ. Leipzig, 1834.

‡ Young's Croonian Lecture on the Functions of the Heart and Arteries, in his Introduction to Medical Literature.

§ Mém. sur le Mouvement du Sang. Laus. 1756. Translated.

|| Expér. sur la Circulation, in French, by Tourdes. Paris, An 8. In English, by Hall. Lond. 1801.

terminations of that fluid which take place in blushing, inflammation, and other states of the economy in which particular parts of the vascular system become more or less filled with blood than usual; for such variations in the distribution of the blood would be impossible, were an alteration in the powers of the heart alone the only means of modifying the circulation. The questions, however, whether such powers as are possessed by the arteries contribute upon the whole to the progressive motion of the blood or modify only its distribution, are quite distinct from one another.

In its anatomical structure the fibrous coat of the arteries differs considerably from muscular substance, and appears to resemble more nearly the yellow elastic ligamentous tissue. Its fibres are less mixed with cellular substance than those of muscles; they are also more dry, hard, and friable, less coloured, and, according to Hodgkin and Lister,* are destitute of those transverse striæ or lines observed by the microscope in ordinary muscular fibres. The chemical constitution of the middle coat of the arteries differs also from that of muscle, for it is less soluble in acetic acid, and more easily so in mineral acids, and it is believed by Berzelius and Young not to contain the animal principle, fibrine, peculiar to muscular flesh. Although we fully admit the importance of these observations as establishing anatomical and chemical distinctions between muscular substance and the texture of the middle coat of the arteries, they do not appear to us to warrant the conclusion too hastily deduced from them by some, that this coat cannot be irritable, or does not possess any of the same properties as muscle, the existence or non-existence of which must be ascertained principally by physiological evidence. For the transverse striæ cannot be considered as characteristic of all muscular fibres; and were we to reason in this way from the result of anatomical observations only, we should be necessitated to deny the irritability of various other textures, the contractility of which from stimulation or without it, is universally admitted, although anatomists have not yet detected muscular fibres in them.

The coats of the smaller arteries are generally believed to be proportionally thicker than those of the larger trunks, and John Hunter held the opinion that the yellow fibrous tissue exists in greatest quantity in the larger arteries; while the smaller vessels, considered more active, are composed of a substance more nearly allied to muscular fibre. The grounds upon which the latter opinion rests are upon the whole not very satisfactory; and it appears to be opposed by those instances in which, after the closure by ligature of the principal artery of a limb, the smaller collateral vessels which maintain the circulation, after undergoing a rapid enlargement, assume the structure and general appearance of the large arteries.

The irritability of the smaller arteries, now very generally admitted by physiologists, though it seems by some to have been inferred from analogy, and to have been rendered probable by Dr. Wilson Philip's observations on the effect of chemical stimuli in removing the dilated state of the capillaries in inflammation, was first distinctly proved experimentally by Dr. Thomson of Edinburgh,* who caused the arteries in the web of the frog's foot to contract powerfully by the application of mechanical irritation as well as by chemical stimuli. His experiments shewed that the nature of the contraction produced by stimulation of one of the smaller arteries varies considerably, occupying sometimes a greater or less space of the vessel, and being at other times confined to one place, sudden, and frequently so great as completely to stop the passage of blood. They also demonstrated the fact that the contraction of the small arteries does not follow immediately the application of the stimulus, as occurs in the voluntary muscles, but that a period of from one to three minutes elapses before the contraction begins, and that the vessel remains constricted for some time, and then returns to its original state, unless inflammation shall have occurred, in which case it dilates to a greater size than natural. The irritability of the small vessels has been fully established by experiments similar to those of Dr. Thomson, by Dr. Wilson Philip,† Dr. Hastings,‡ Kaltenbrunner,§ and Wedemeyer,§ the last of whom succeeded in causing the small arteries to contract by means of galvanic as well as of mechanical irritation. The constriction which follows the injection of styptic and irritating fluids into the arteries, observed by Hales‖ in animals recently dead, and similar experiments by Wedemeyer, may be adduced as another proof of their irritability. The stoppage of hemorrhage from cuts of the small arteries and capillaries, assisted as it is by cold or irritating applications, may be regarded as the effect of the same property.

Contractions do not occur so readily or obviously in the large as in the very small arteries. Verschuir appears to have been the first who observed, in a manner not liable to fallacy, distinct contractions of the larger arteries to occur after the direct application of a stimulus. From an extended series of experiments upon this subject, described in his Inaugural Dissertation De Vi Arteriarum Contractili, Verschuir was led to adopt the opinion that the arteries are possessed of irritability, or contract in the same manner as muscles do from irritation; as he observed very obvious and powerful contractions to occur when, by means of a sharp point or chemical stimuli, he irritated the coats of the larger arteries of animals.

Haller, though considering the middle coat of the arteries as of a muscular nature, was unsuccessful in producing obvious contractions in them. The repetition of the experiments of Verschuir by many others has been attended with very various results; some confirming his observations, others having entirely failed in producing any obvious contraction, or not being disposed to consider it of a muscular kind. Among the last may be mentioned Nysten, Bichat, Wedemeyer, and J. Müller.

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* Appendix to the Transl. of Edwards's Work on the Influence of Physical Agents, &c. p. 443.

* Lect. on Inflammation. Edin. 1813.

† Introduct. to the second part of his work on Fever.

‡ Introduct. to his work on the Inflammation of the Mucous Membrane, &c.

§ Exper. circa statum Sang. et Vasor. in Inflammatione. Munich, 1826.

‖ Untersuch. über den Kreislauf des Blutes, &c. Hannover, 1828. See also Koch in Meckel's Archiv. 1832, p. 121.

¶ Statical Essays, ii. p. 124.

It must be obvious that, laying aside the difference of opinion regarding the nature of the contractions when they are admitted to occur, in a question of this kind a positive result deserves more consideration than a negative one, provided the phenomena stated to have been observed are such as to be appreciable by all. Among the experiments favourable to the view that the large arteries are endowed with irritability, may be mentioned those described by Hastings,* and a series of unpublished observations by Dr. Thomson, to which we have access, which seem to prove in a very satisfactory manner the frequent occurrence of contractions in the larger arteries after stimulation; and to point out as a cause of the failure of some at least of the previous experiments, the long time which commonly elapses between the application of the stimulus and the occurrence of the contraction; together with the circumstances formerly remarked by Verschuir, that the contraction is not an invariable consequence of the stimulation, and that it occurs much more readily in some animals than in others.

According to Dr. Thomson the contraction of the larger arteries is in general not perceptible before from three to ten minutes after the application of the stimulus. When galvanism is used, the shocks need not be strong, but must be frequently repeated in order to induce contraction.

Many have remarked the gradual or sudden contraction of the trunks of arteries which have been laid bare in Man as well as in the lower animals. When exposed, an artery is sometimes equally contracted for some length along its tube; at other times its surface assumes a waved appearance from the occurrence of irregular contractions or alternate contractions and dilatations, and not unfrequently the coat of the artery is much constricted at one point only, as if a tight cord had been passed round it. Appearances of this kind, which seem to indicate very distinctly the possession of the property of irritability by the arteries, are well known to many surgeons; they were noted by Drs. Jones and Thomson, in the experiments upon which Dr. Jones's work on Hemorrhage was founded; and also by Dr. Parry, who nevertheless refuses to consider them as irritable contractions. At p. 74 of his work on the Powers of the Arteries, Dr. Parry, referring to Experiment 13th, says, "thus a very narrow ring of the carotid became, while it was under examination, contracted as if a small ligature had been half tightened around it." So also in Experiment 24th, he relates that a part of the carotid artery of a ewe was diminished by a third of its original diameter under exposure, after having been half an hour denuded, while the neighbouring parts had become rather dilated, and that while he was proceeding to measure one of these dilated portions, he "saw it shrink to nearly the same size as the constricted part." It appears to us manifest, that, whether these irregular diminutions of the diameter of the artery, obviously occasioned by a shortening of its fibres, are attributed to the exposure of the artery to the air, or the violence done during the dissection of it by the scalpel, they must equally be regarded as the consequence of stimulation of one kind or other, and are therefore of the nature of muscular contractions.

Hoffmann first noticed the contractions of the arteries from the application of acrid chemical stimuli to their coats; and it appears from numerous subsequent experiments, that contractions are more readily induced in this than in any other way. Were there no other proofs of the contractility of the arteries than those derived from the effect of chemical agents, we should not feel inclined to place much reliance on them, on account of the possibility of there having been induced a permanent alteration of the texture from chemical action; but the results of such experiments form an important confirmation of those which are performed with mechanical and galvanic irritation. We cannot, however, acquiesce in the opinion of Wedemeyer* and others who compare the distinct and well-marked contractions of particular parts of the arterial tubes, such as those above alluded to, to the general constriction of other textures, and more particularly to the shrinking of the skin which occurs from the influence of cold, passions of the mind, &c.

From these considerations we are induced to adopt the opinion that the contractions which under certain circumstances occur in the arteries resemble muscular contractions more nearly than any other vital phenomenon. The positive evidence of direct experiment obviously proves that the contractions in general follow the application of some stimulus to the artery; but these contractions differ from that of muscular parts chiefly in the length of time which elapses after the application of the stimulus before the change of size begins, in the slowness with which the contraction is succeeded by relaxation, and in the want of obvious correspondence between the force of the stimulus and the extent of contractions which follow it.

Besides the more marked contractions of parts of their tubes, the arteries are subject in various circumstances to undergo a slow and gradual diminution of their diameter throughout their whole length, which is considered by many physiologists to indicate the possession by them of a property of the nature of contractility different from irritability in its phenomena and the causes which call it into action. A power of a similar kind, to which the name of Tonicity is applied, is believed to reside in the voluntary muscles.*

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* Inaug. Dissertat. Edin. 1817, et loc. cit. See also Hunter on the Muscularity of the Arteries, Edin. Med. and Surg. Journ. xxii. p. 256.

* Loc. cit.

The experiments and observations generally stated in proof of the tonic power of arteries are the following: —

1. When a ligature is placed upon an artery of a living animal, the part of the artery beyond the ligature becomes gradually smaller, and is emptied to a certain degree, if not completely, of the blood it contained.

2. When a part of an artery in a living animal is isolated from other organs by means of two ligatures and punctured, the blood issues from the orifice, and the enclosed portion of artery is nearly completely emptied of its contents.

3. The empty condition of the arteries generally found after death is believed to be, in part at least, produced by a slow contraction of the whole of the large arterial tubes; for it has been observed, that some hours after death the arteries are much diminished in size, and this occasionally to such an extent as to be rendered impervious, as was observed in the umbilical arteries of the navel string by John Hunter† and others.

4. It has been shewn by Poiseuille‡ that when a portion of an artery from an animal recently dead, and one from an animal that has been dead for some days, are distended with an equal force, the portion of the artery from the recently dead animal becomes more contracted after the distending force is removed than the other one.

5. In the last place, when a large artery is divided, the cut extremities frequently become so completely constricted as wholly to prevent the issue of blood, and this kind of contraction is well known to occur in a greater degree after laceration of an artery than after division by the knife: hence the less danger to be apprehended from hemorrhage in lacerated than in incised wounds; and thence the possibility of producing the closure of one of the larger arteries by the mere compression or torsion of its cut end.

In the three last-mentioned proofs of tonicity the contraction of the artery followed the application of some kind of irritation; for the exposed artery was dissected out by the scalpel, and ligatures were tightened round it, the coats of the artery were stimulated by distension in Poiseuille's experiment, and in the twisting or torsion as well as in the division of an artery by laceration or cutting there is always an irritation applied to the contracting part. The tonicity or tonic contractility therefore was in some of these instances first called into operation and in others increased by irritation, and ought not therefore to be distinguished from irritability as regards its cause, but only as relates to its phenomena.

The evacuation of the blood from arteries beyond the place at which they have been tied in the living body, and the contraction of arteries which takes place in the dead body, as well as the rigidity of muscles soon after death, or their retraction when divided in the living body, all seem to indicate a tendency in irritable parts to undergo a slow and continued contraction during the persistance of their vital powers. This tendency to contraction seems to differ from the shortening and subsequent relaxation which are the more or less immediate effects of stimulation in truly irritable parts, and it seems to be more dependent upon the removal of the forces by which the parts in which it occurs are kept in a state of distension than upon any other cause.

It is obviously in consequence of this tendency to contract when not distended by a force from within, that the arteries are always nearly accommodated to the quantity of blood contained in them. But while we are constrained to admit the existence of the peculiar slow contractile power in arteries appropriately denominated tonicity, we would caution the accurate physiologist against considering as the effect of this property rather than of irritability any of those contractions of the arterial tubes which are induced or increased by mechanical, galvanic, or other stimuli.

e. Influence of the vital powers of the arteries on the circulation.—Let us now inquire in what manner the flow of the blood is influenced by the irritability and tonicity of the arteries.

Some of those who have regarded the arteries as contributing by their active powers to propel the blood have conceived it sufficient for them to prove that there is a necessity for some additional force in the circulation besides that of the heart, in consequence of the total expenditure of the heart's force from the windings of the small vessels, the friction of the blood against the side, and other resistances to be overcome in the capillary system. This expenditure of the heart's power admitted by many on insufficient grounds has been very generally overrated. Although the causes just mentioned may diminish to a certain extent the propelling power of the heart, there are various very simple experiments which shew that the heart's action is propagated with a propelling effect through the whole vascular system, so as to act in the extreme vessels and veins.

In the first place, Haller, Spallanzani, Thomson, and many others have observed in the transparent parts of animals that the impulse of the heart is transmitted to the very ends of the small arteries, which may be less than $\frac{1}{500}$th part of an inch in diameter, and that in some states of the circulation the impulse of the heart is continued on through the capillary vessels and into the commencements of the veins. The fact that this generally occurs when the action of the heart is weakened, and when the vessels are consequently not sufficiently distended by its impulse to react by their elasticity and convert the remitting into a uniform force, is a distinct proof that in the natural state of the circulation a greater proportion of the force of the heart must be transmitted through the blood to the capillaries, and must act through them upon the column of blood returning in the veins.

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* Parry, loc. citat.

† On the Blood and on Inflammation.

‡ Magendie's Journ. vol. viii.

From the same experiments it has appeared that in general the instant any obstruction prevents the action of the heart from being propagated onwards in the arteries, the progressive current of the blood in the small vessels becomes slower and soon ceases, any motion which goes on afterwards being quite of a different kind from that occurring in the natural circulation.

An experiment performed by M. Magendie, and formerly referred to, also affords a very satisfactory proof that the heart's force acts in propelling the blood through the whole vascular system. M. Magendie dissected the femoral artery and vein separate from the neighbouring parts, and passing a ligature under them tightened it round the whole limb, excepting the two principal bloodvessels, through which the blood was allowed to flow freely. He was thus enabled to shew that the flow of blood from an orifice in the vein was immediately dependent on the force of the heart acting through the artery, as it was suddenly diminished and soon completely ceased the instant that the latter vessel was obstructed, and became more or less rapid according as it was more or less compressed. We would further remark that the experiments of Hales and Poiseuille, more particularly the latter, have shewn that there is little if any difference in the force of the blood in arteries of very different size.

On the other hand, it appears to us sufficiently clear that the occurrence of any general contraction of the coats of the arteries would have the effect of opposing an obstacle to rather than of assisting the progress of the blood in the arteries, just in proportion to the degree of the force of the heart, which would necessarily be expended in dilating them to the required size, in order to allow of the free transmission of the blood by them; and as, according to the commonly received opinion, the contractile powers are greater in the smaller than in the larger arteries, the operation of this contraction would be much the same as the diminution of the aperture through which blood flows from an inorganic tube, and would thus cause a still greater obstruction to the flow of blood than a general contraction. It is only on the supposition that the arteries undergo an undulatory or vermicular contraction, proceeding from the larger to the smaller branches, that this contractile force can be believed to contribute to the progressive motion of the blood, because then it might be conceived to assist the elasticity of the arterial parietes in propagating the force of the heart along the column of contained blood, and even augment this force by an additional power. But we would remark that no such vermicular action has been ascertained to occur by any observations or experiments with which we are acquainted; that in artificial injection of fluids into the large arteries of dead animals a force of a few pounds is found to be sufficient to propel these fluids, when not of an irritating kind, from the arteries into the veins; and that it follows from the direct experiments of many, more particularly those of Hales, Poiseuille, and Magendie, that the action of the heart, transmitted by the elastic arteries, is the only cause operating in the progressive propulsion of the blood in arteries of such a size as to admit of the force of the blood being measured in them.

In asserting, however, that a general contraction of this kind, if it occurred in the vascular system, would upon the whole obstruct or retard rather than assist the progressive motion of the blood in the arteries, we would not be supposed to deny that the vital powers of the arteries may modify very considerably the distribution of blood to different parts, for it is manifest that an increased action occurring in one part of an artery may hinder the blood from being transmitted in its usual quantity into a neighbouring part, while a dilated state of an artery or its branches, or, if we please to call it so, a diminished action or greater weakness of resistance of the coats of the artery considered relatively to the powers of propulsion operating through it, may occasion the flow of a greater quantity of blood to a part, as occurs in local inflammations. Among the many indirect arguments adduced on both sides of this question may be mentioned the following. In the first place, the fact that in the lowest classes of animals, as in Vermes and Insects, which have no proper heart, the bloodvessels propel the blood by their contractile power, and that in some of the higher animals, particularly Reptiles and Fishes, parts of the vascular system, as the bulb of the aorta, a considerable portion of this vessel, parts of the veins, and so on, are distinctly contractile, and assist the powers of the heart, are adduced as proofs from analogy that the arteries in warm-blooded animals may have the same power and perform the same function. Now it may be answered to this, that the circumstance of the lowest classes of animals having no proper heart is the final cause of or an obvious reason for the greater contractility of these vessels; and in the second place, that no rythmic contraction is observed to occur in the arteries of warm-blooded animals of the same nature as that observed by Haller, Spallanzani, M. Hall, and others in the bulb of the aorta and other parts of the vascular system of cold-blooded Vertebrata. For similar reasons we are not inclined to attach much importance to the argument in favour of the independent powers of the arteries deduced from the alleged occurrence of circulation in acephalous fœtuses, in all of which the proper muscular heart seems to be wanting; for although the distribution of the vessels in these fœtuses has been sufficiently accurately determined, the nature of the circulation which occurs in them is a subject involved in the greatest obscurity. There seems good reason to doubt that such fœtuses have ever existed alone in the uterus, in which case their vessels may, as is known in many of them to have occurred, have been connected with those of a perfect fœtus; and even were this not the case, the absence of the heart might be attended in these malformed productions with an unusual development of muscular power in parts of the vascular system.*

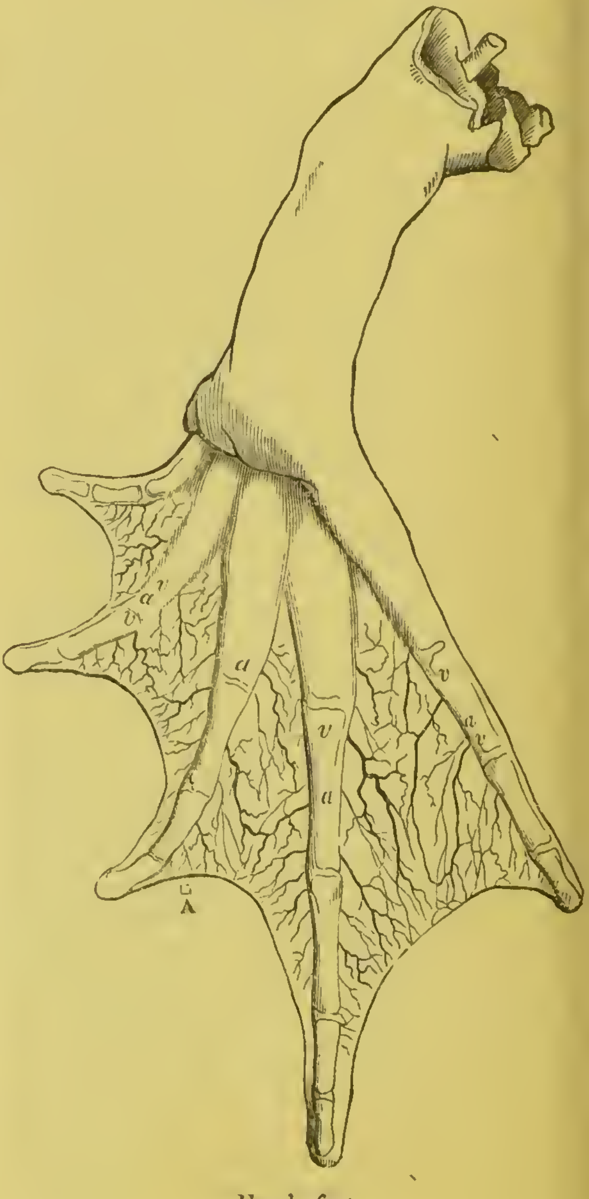
In conclusion, we may remark that the argument drawn from the occurrence of circulation apparently little impaired through arteries which have been completely ossified for a considerable time, seems to be very much in favour of the view we have taken that the heart alone is the cause of the progressive flow of blood through the arterial tubes.

3. *Phenomena of the capillary circulation.*—The phenomena of the passage of the blood from the terminations of the arteries into the commencement of the veins through the capillary vessels, are highly interesting and important in many points of view, for the immediate respiratory change which the venous blood undergoes in the pulmonary vessels, and all those alterations of composition which accompany nutrition, growth, secretion, and other organic processes connected with the systemic vessels, occur in the smallest ramifications of the pulmonic and systemic circulation, and the morbid state of inflammation as well as the various pathological changes which occur as its consequences are intimately connected with an altered condition of the capillary system.

a. Structure and distribution of the capillary vessels.—The name of capillary is generally given to all those minute vessels which form the means of communication between the small ramifications of the arteries and veins; but there is some difference in the opinion of anatomists and physiologists as to how much of the vascular system ought to be included under the division of the capillary vessels. Some, adhering to the strict meaning of the term, apply it to all the small vessels whatsoever under a certain size; others hold that between the extremities of the arteries and veins there is always situated a series of minute tubes of nearly equal size in their whole length, and not ramifying like the arteries or veins, which constitute a system of vessels distinct from the others in their structure, distribution, and properties, to which the name of capillary ought to be restricted.† The last view appears to us to be founded in a partial acquaintance with the system of minute vessels, for though it may be true that in some parts of animals the capillaries have obviously the structure above described, and seem to form a system of vessels apart from the smaller arteries and veins, yet this is by no means the case in other textures; and we think that the more extensive observation of the structure of these vessels in various parts will shew that in the greater number, as is well ascertained to exist in many, the smaller arteries pass into veins quite in a gradual manner, the ramifications of each class of vessel becoming more and more minute until they meet, the two kinds of vessel presenting no difference of character other than the change of direction assumed by the moving blood, which enables us to say with certainty where the artery terminates, and at what point the vein begins, and affording thus no reason to consider the continuous tube by which they join as different in structure from either the minute artery or vein. While we acknowledge therefore the importance of the observations which point out the existence of capillary vessels of a uniform size in some textures, we think it necessary to retain the name of capillary as applied to all the minute vessels, both for the reason that the communicating vessels are not every where of the same kind, and that from the use already made of the term by physiological writers its meaning will thus be more easily understood.

The vessels which lead from arteries to veins are of very various sizes, some admitting only one globule at once, others being so large as to allow of the passage of three, four, or even a greater number of red globules together. In tracing with the microscope the motion of the minute streams of blood as they pass through the capillary vessels, the eye is guided by the

Fig. 19.



Frog's foot.

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* See the Researches of Elben, Tiedemann, Breschet, and others on Acephalous Monsters.

† Dr. Marshall Hall's Essay on the Circulation of the Blood, Lond. 1831. Dr. James Black's Short Inquiry into the Capillary Circulation, Lond. 1825.

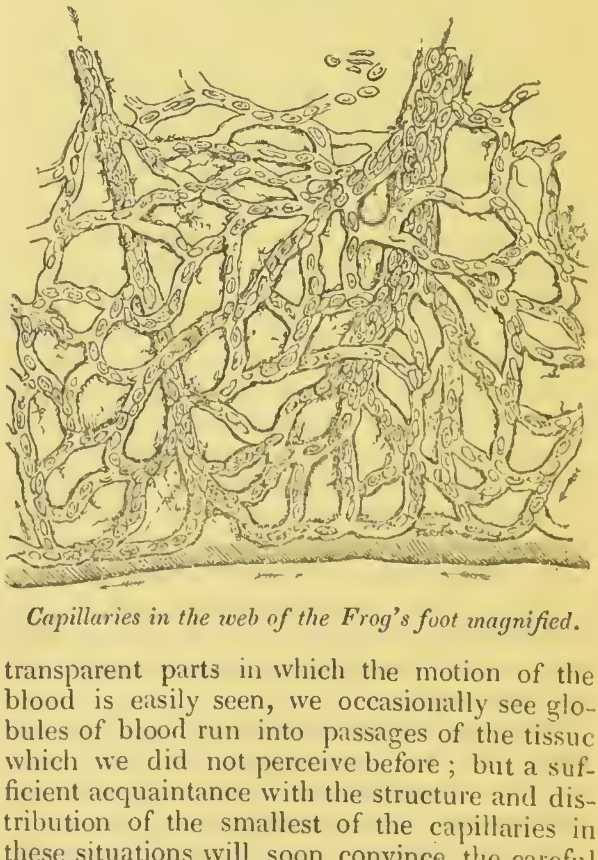
motions of the red globules principally, for it is very rarely indeed that the current of fluid which carries the globules along can be recognized in the ordinary modes of observation.

The capillary circulation is most easily seen in cold-blooded and in young animals, both on account of the large size of the red globules and the small number of the vessels. Since the first discovery of the capillary circulation by Malpighi, the transparent web between the toes of the hind feet of the frog has been universally adopted as the most convenient situation for observing this beautiful spectacle with transmitted light. The fins and tail of fishes, the tail of the larva of the Frog and Newt, the external gills of the same animals as well as of cartilaginous fishes, the mesentery of the Frog or of small warm-blooded animals, the wing of the Bat, the lungs and urinary bladder of Reptiles, the liver of the Frog and Newt, the membranes of the incubated egg, the yolk of the Skate's egg, are all situations favourable for the observation of the capillary circulation. The capillary circulation has been viewed in only a small number of warm-blooded animals, and in very few of their textures; but the minute injection with coloured fluids of all parts of the bodies of Quadrupeds and of Man leaves little doubt that in them also, whatever varieties there may be in the size, number, and distribution of the small vessels, the blood passes in every organ from the small arteries into the returning veins by minute continuous tubes of the same nature as those more easily observed in the situations above-mentioned.

Some are inclined to consider the minutest or proper capillary vessels as destitute of vascular parietes, and consisting of mere passages through the texture of the organ in which they exist without any lining membrane. This opinion is founded on the impossibility of seeing the coats of the vessels, the rapidity with which new capillaries may be developed, and some other circumstances. The extreme degree of minuteness of the smallest capillary vessels must render futile any attempts to decide this question by direct observation. Besides the general analogy between the larger and smaller vessels, there are several circumstances known which seem to be strongly in favour of the view that the capillaries do not differ in this respect from other vessels. 1st, It is allowable to suppose that the active properties of the capillary vessels belong to parieties as in the larger vessels. 2d, In many transparent parts of animals in which the terminal arteries and veins do not diminish to a very small size, the coats of the vessel may be seen with the microscope, as in the external gills of the Amphibia, and in the vascular rete of the ear of birds and reptiles, in which the capillary vessels may, after having been injected, be separated from the neighbouring soft texture. 3d, The conversion of small into larger vessels with visible coats in those instances in which the course of blood through the vessels of a part has undergone an alteration, is in favour of the previous existence of parietes in the smaller vessels. And 4th, The constant and regular distribution of the minutest vessels in many parts of animals appears to support the same view. The argument in favour of the non-existence of capillary parietes deduced from the alleged facility with which the blood occasionally passes out of the regular vessels and takes an irregular and indeterminate course through the non-vascular parenchyma of an organ, we believe to be founded, in some instances, in peculiarities belonging to a few parts only, and in others in inaccurate observation; for in almost all those situations in which the capillary circulation may be seen with ease and distinctness, the constancy of the minute passages which the blood permeates is undoubted.

From the more accurate means of making minute anatomical researches that have been introduced in modern times, the existence of serous, exhalent, and white vessels has become a matter of great doubt, for vessels of this description which do not admit the red globules and liquor sanguinis together cannot be made obvious to the senses by the most delicate injections or dissections; and the observation of the capillary circulation in the transparent parts of animals affords the most convincing proof that the smaller arteries have no visible terminations excepting in the capillaries and small veins. In observing attentively the web of the frog's foot and other transparent parts in which the motion of the blood is easily seen, we occasionally see globules of blood run into passages of the tissue which we did not perceive before; but a sufficient acquaintance with the structure and distribution of the smallest of the capillaries in these situations will soon convince the careful observer that the vessels into which the blood was seen to pass, apparently for the first time, existed fully formed before, that the fluid part of the blood passed in part through them, and that the stoppage of the red particles was to

Fig. 20.



Capillaries in the web of the Frog's foot magnified.

a great measure dependent on partial or local impediments. The compression of one of the small arteries, for instance, will frequently, after causing oscillation of the globules of the blood in the smallest capillaries, be followed by the disappearance of some of them; but in a very short time, or when the obstruction is removed, the blood regains its former velocity and force, and flows into exactly the same passages as before.

The notion that the smaller vessels are continuous with the smaller lymphatics, and more especially with the excretory ducts of glands, seems to be fully disproved by the accurate researches of Malpighi, Mascagni, Panizza, Müller, and Weber, which have shewn that the lymphatic vessels originate at all parts of the body by a plexus of tubes every where closed, and that the excretory ducts of secretory organs begin always by shut ends.

We believe it to be satisfactorily shewn that in the whitest of the textures (with the exception perhaps of the cornea and crystalline lens), there is no necessity for the supposition of vessels admitting the fluid parts only of the blood, or of serous vessels, as they have been termed; and that in all of them there exist small bloodvessels which admit very fine rows of globules in their accustomed proportion to the fluid part of the blood: for many textures which appear perfectly white or colourless, or only slightly yellow when viewed with the naked eye, are found, when examined with the microscope, to have small vessels carrying blood globules through them. Spallanzani and others shewed that very small vessels taken singly or seen in very thin layers have almost no perceptible colour; and it is a well known fact that, in what are called the red textures, the colour (as of muscle for instance) is not exclusively dependent upon the quantity of red blood in them. It is difficult, indeed, to conceive how the circulation of the blood could be carried on at all, or how the red particles of the blood could ever be returned to the heart were the globules to be retained in the larger vessels, and all the white textures to admit only the fluid parts of the blood.

In adopting the opinion that the arteries terminate always by direct continuity of tube in the veins, and that no other visible passages are connected with the minute vessels, we must suppose that the various interchanges of materials occurring between the blood and the organized textures or foreign matters, as in nutrition, secretion, respiration, transpiration, &c. must take place by some process of organic transudation through invisible apertures of the minute vessels.

b. Properties of the capillary vessels and influence on the circulation.—From the experiments already referred to, it is apparent that the smaller arteries, so long as they can be distinguished from other vessels, are capable of being excited to contraction by the application of a stimulus; but we have no means of shewing this with regard to the minutest capillary vessels, because we can scarcely apply any stimulation to them without affecting some of the smaller arteries at the same time. When it is said, for example, that the capillary vessels are irritable, because the application of ammonia or spirits of wine causes them to become smaller, it is difficult to determine how far this appearance of diminished size in the capillaries depends on their receiving less blood, in consequence of the contraction of the small arteries leading to them or upon the less size of these vessels themselves. In the experiments of Dr. Thomson and others, however, the application of salt and other stimuli exciting inflammation have appeared to dilate even the smallest capillary vessels, and such a dilatation can scarcely be considered as indicating any thing else than a less power of resistance in these vessels; and when the application of ammonia or spirit of wine restores such dilated capillaries to their natural condition, we do not see that any other natural inference can be drawn from this fact than that the capillaries have been contracted by the influence of these stimuli; for the contraction of the small arteries alone, although it might restore the lost velocity of the blood, would not diminish the capillaries to their former size. This general diminution of size ought however to be carefully distinguished from the more marked and local contractions of true arteries.

The velocity of the blood is quite uniform in the capillaries of the adult animal in the natural condition of the circulation. There is reason to believe the capillary vessels to be highly elastic, and to have the effect of completing the change which is begun by the arteries, viz. that of equalizing the force of the heart transmitted through the blood. We do not, in observing attentively the capillary vessels, ever perceive any motions of alternate dilatation and contraction of their sides. The blood flows through them as through small glass tubes; and if they act by other powers than by their elasticity alone, this action must be of so slow a kind as not to be perceptible. There can be no doubt that any action of contraction occurring in the capillary vessels, whether alternating with dilatation or not, could have no effect excepting that of obstructing the passage of blood through them. It would act upon the contents of the arterial system much in the same way as the diminution of the aperture at the end of a rigid tube would affect the flow of fluid through it, that is, either a less quantity of blood would pass through the capillary vessels in consequence of their less size, or a greater portion of the heart's force would be expended in dilating these vessels to a sufficient extent.

The principal reasons which we feel inclined to adduce for believing that the heart's action is continued onwards through the capillaries, and is sufficient to return the blood through the veins back as far as the heart itself, are the following:—1. That in an animal recently killed a very small force only is requisite to cause bland fluids to follow the course of the blood, provided the injection be made before the tonic contraction has had time to constrict the vessels. 2. The experiments of Hales and Wedemeyer shewing that, according to the more or less stimulating character of the fluids, their passage through the vessels was more or less easy. 3. The experiments shewing that, in an animal which has been dead for some time, steeping of the body in warm water, and the injection of warm water into the vessels, so as to clear the passage through them, puts the vessels in such a condition that a force of a few pounds is sufficient to effect the propulsion of fluids through them. 4. The observations of Haller, Spallanzani, Magendie, and others, that all regular progressive motion of blood in a vein, or the issue of blood from an orifice in a vein, ceases very soon after the heart's action is suspended, or when any obstacle prevents its force being communicated to the blood in the veins. 5. The observations of Spallanzani, Thomson, and others, that the impulses of the heart are visibly continued on through the small arteries and capillaries, and even into the veins in some states of the circulation. This phenomenon is most apparent at the time when the action of the heart is weak, and in such states of the circulation this remittent flow of the blood may be converted into a merely oscillatory movement without any regular progression by the gradual increase of the pressure applied to the artery which supplies the blood to the capillary vessels under observation; a fact which shews distinctly on the one hand that the force of the heart is continued on through the capillaries, and on the other that when a resistance is opposed to the progress of the action of the heart through the arteries, no other force then operates sufficient to cause a continued and progressive motion of the blood.

But, although the small vessels do not contribute by their active contraction to propel the blood through them, or although they do not as a whole assist the force of the heart, it is yet very apparent that they have the power of modifying in a remarkable manner the flow of blood in particular parts. Among the circumstances which prove this power of the small vessels to modify the circulation may be mentioned the various instances in which there occur local determinations to particular parts, unaccompanied by any change in the action of the heart or in the general circulation. 1. The act of blushing and erection, or the reverse actions of paleness, collapse, &c. which seem to depend, in most instances at least, on some change in the terminal vessels 2. Inflammations or hemorrhages confined to a particular part of the body. 3. The increase or decrease of secretions from glands, periodical or instantaneous. 4. The increased size of the vessels of the uterus during pregnancy, of the mammæ after child-birth, &c. 5. The enlargement of bloodvessels in new growths, tumours, &c. 6. The enlargement of collateral anastomosing vessels, after the closure of the principal trunk of a limb. And, 7. The unequal growth or development of different parts of the fœtus. Although we do not understand the nature of the change in the vessels which accompanies these partial distributions of blood to particular parts, yet they all sufficiently demonstrate that while the heart's action remains the same, the quantity of blood sent to particular parts must have been modified by some action of the vessels themselves.

There are some physiologists, however, who hold the opinion that the motion of the blood is promoted in some way or other (they do not sufficiently clearly explain how) by powers acting on it during its passage through the capillary vessels; and there are a few who have gone so far as to suppose that the heart drives the blood only as far as the capillaries, from whence it is propelled onwards into the veins by powers originating in the small vessels themselves. These opinions have been supported chiefly by arguments drawn from the facts already mentioned as illustrating the power of the small vessels to modify the circulation or to cause local variations in the distribution of the blood, as also on the following grounds, which are ably stated in a supplement to his Outlines of Physiology,* recently published by Professor Alison, of Edinburgh, who is one of those who have more lately adopted this opinion, and by Dr. Black in an ingenious essay on the capillary circulation.†

Besides the analogical argument drawn from the lower animals having a circulation of fluids without any heart, and the supposed unaided circulation in acardiac fœtuses, it is stated that—

1. After the heart of the frog or such cold-blooded animals has been cut out, or a ligature passed round the aorta, some motion of the blood still continues to occur for a few minutes in the small vessels; and it is farther stated, that this motion is influenced by heat, by certain applications to the web of the frog's foot, and the state of the nervous system.‡

2. That while the circulation is going on with its usual freedom, the direction and velocity of the flow of blood are subject to sudden or rapid changes which do not admit of being accounted for simply by contractions of the vessels.

3. That the blood when out of the vessels, immediately after it has been drawn, or when extravasated in the textures, performs motions which seem to belong to itself or are spontaneous.§

4. That the passage of the blood through the capillary vessels of the lungs is immediately influenced by the chemical change of the venous blood into arterial, for its velocity is diminished as soon as this change does not occur.||

5. That the remoteness of the capillaries of the vena portæ of the liver from the heart ren-

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* Outlines of Physiology, Supplement to 2d edit. Edin. 1836.

† London, 1825.

‡ Haller, Guillot, Leuret and Wilson Philip, Marshall Hall, and others.

§ Kielmeyer, Treviranus, Carus, Czermack, Œsterreicher, and Schultz.

|| Dr. Alison, loc. cit.

ders probable the existence in them of some power capable of propelling the blood independently of the heart's action.

6. That in the production of new vessels which occurs in adhesion or granulation, the new blood executes oscillatory motions in the rudimentary vessels while in the act of forming, before these parts of vessels are connected with the previously existing branches through which the heart propels the blood; and this is said also to occur in the formation of new vessels in natural growth.[*]

7. That in the formation of the vascular area of the incubated egg the blood moves in part through the veins and small vessels before it is impelled by the action of the heart.[†]

We would remark, regarding the oscillatory and irregular motions described by Haller and others as occurring in the small vessels of the web after removal of the heart or ligature of the aorta, that we believe some of these to be caused by the elasticity of both the arteries and veins, and others to be occasioned by the gradual or tonic contractions which take place in the arteries after death:[‡] they occurred in all Haller's observations, but in Spallanzani's only when the apparatus of hooks constantly employed by Haller was applied; and so far as we have ourselves been able to observe them, we have always found them influenced by very slight changes. When one of the small vessels is obstructed they cease altogether, which ought not to be the case were they dependent upon powers belonging to the capillaries or the blood in them. Some varieties in the velocity and direction of the blood in the smaller vessels we have reason, from our own observations, to attribute to the same causes, and we think it consonant with such a supposition that heat or other agents influencing the contraction of arteries should influence these irregular motions. The oscillations of blood in parts of vessels which are in the process of formation in adhesions and granulations, or in natural growth, we have not yet been able to observe so clearly as to be certain that we were not deceived; but, even supposing them to have been satisfactorily proved to occur, we should be inclined to doubt the possibility of ascertaining with accuracy that these portions of vessel are entirely shut off from all communication with other vessels, so as that no impulse could be transmitted from the heart to them. The necessity of some change in the tissue of organs or of organizable lymph, in which new vessels are about to be formed before the propulsion of the blood into the new loop of vessel seems sufficiently obvious, but it does not appear to be as yet satisfactorily shewn that the motion of blood in the new vessels is independent of a propulsion received from the heart. Again we consider it as ascertained that the heart of the chick acts just as soon as any motion of fluids can be seen on the vascular area of the yolk; and though it may be admitted that a certain change of place in the particles of the yolk is necessary in the new combinations which occur during the development of the forming parts from its substance, yet such a change or motion must be quite of an insensible kind and not in any degree analogous to the continued stream of circulating blood through the vessels.

The stagnation of venous blood in the capillaries of the lungs is certainly a most remarkable and inexplicable phenomenon, but if from analogy any weight is to be attached to observations made upon the frog, it may be stated that the flow of blood through the lungs seems as immediately dependent on the heart's action as that through the system. The portal circulation is not more remarkable in respect of its isolation from the heart than the systemic circulation of fishes, in which animals the capillaries of the gills intervene between the heart and the systemic aorta; and without any distinct contraction of that vessel, the circulation of the blood in the systemic capillaries as well as in the gills is very manifestly maintained chiefly, if not solely, by the action of the heart. We do not feel inclined to attach any importance to the alleged motions of the globules of the blood out of the vessels, for we have never been able to see any such indicating different powers from those which produce currents in inorganic fluids, and some of the observations upon which the statement is founded have been shewn to be erroneous.

We think it unnecessary to do more than merely to allude to some of the very many attempts that have been made to account for independent motion of blood in the capillaries, or what have been termed the theories of the capillary circulation.

All that we know of capillary attraction militates against the possibility of its being the means of causing a progressive motion of fluids, such as that which occurs in plants and animals. Those who have attributed the motions of fluids in the living body to endosmosis or a principle of organic transudation, have failed in pointing out in the bloodvessels the conditions necessary for the occurrence of a motion proceeding from an action of this description. The electrical theory is defective in this essential point, that no difference in the electrical condition of the arterial and venous blood has been shewn, and that the same cause to which the motion of the capillaries of the systemic arteries is ascribed ought to retard the passage of blood in the pulmonary capillaries, the relations of the two kinds of blood being there reversed. The opinion that the motion of the blood in the vessels is analogous to those currents of fluids which take place in contact with the surfaces of various parts of animals, which are almost always connected with ciliary motions, and are described under the head of Cilia in this Cyclopædia, is defective in so far as neither cilia nor any power of exciting currents has yet been shewn to exist in the interior of the bloodvessels, and they have been examined in circumstances in which we conceive they would have been seen had they been present. In fine we cannot see how any power of spontaneous motion belonging to the blood itself could be a cause of progressive motion of that fluid, unless the direction of the motion were determined by the solid textures containing the blood, and in this case the same objections would apply to this explanation of the cause of motion as to the one to which allusion has just been made; and besides, the evidence of spontaneous motions of the blood appears upon the whole of a very unsatisfactory kind.

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[*] Dœllinger, Journ. des Progrés, &c. vol. ix. Kaltenbrunner, loc. cit. Baumgärtner, Beobacht. über die Nerven und das Blut. Freiburg. 1830.

[†] [Dr. Tanchose suggests as a cause for the motion of the blood in the capillaries, the ceaseless removal of particles from the blood to supply materials to the various secretions, &c. a constant tendency to a vacuum being thereby produced. Acad. des Sciences, Séances d'Avril, 1833.—Ed.]

[‡] See Marshall Hall's Essay, p. 95; and also Black's Inquiry, for judicious remarks upon these oscillations.

From these considerations we find ourselves constrained to hold the opinion that, however great the power which the capillary vessels possess of modifying the distribution of the blood, there is not reason to believe that they contribute as a whole to its progressive motion.

4. *Phenomena of the venous circulation.*—In the natural state of the circulation the flow of the blood is nearly quite uniform in the veins, as may be seen when a vein is opened in the common operation of venesection. In those rare instances in which the flow from a vein is accelerated after each beat of the heart, in the same way as the arterial jet, it may be supposed either that the intermitting impulses of the heart are, from some circumstance or other, transmitted more freely and to a greater distance than usual through the capillary vessels, as is known occasionally to happen, or, what is more probable, that the larger branch of the vein receives the successive impulses directly from neighbouring large arteries, which are more than usually dilatable.

As the size of the veins is generally greater than that of the corresponding arteries at the same distance from the heart, and as they are also more numerous, the velocity of blood is less in these parts of the veins than of the arteries; and as the whole venous system contains considerably more blood than the arterial, the velocity of the blood taken as a whole must be less in the veins than in the arteries. The same quantity of blood must be brought by the venæ cavæ to the right auricle as issues from the left ventricle, (making allowance for the expenditure by secretions, &c.) and consequently the velocity of the blood entering and of that issuing from the heart must be equal. Again, the velocity of the blood must be gradually on the increase in its progress from the small to the larger veins, because the capacity of the vessels into which it flows is gradually becoming less.

In the systemic veins, excepting the venæ portæ, the direction of the flow of blood is determined by the structure of the valves, which permit of the return of blood from the extremities of the veins towards the heart, but oppose, by the filling of their pouches and the apposition of their free edges, a complete obstacle to the reflux of the blood in another direction.

The principal cause of the progressive flow of the blood in the veins is unquestionably the force of impulsion of the heart continued through the arteries and small vessels, as appears from the flow from the remote part of an opened vein and the simple experiments of Hales, Magendie, and Poiseuille already referred to. Hales ascertained, by introducing tubes into the larger veins of the horse, that the pressure on the blood from behind, or *vis à tergo*, is sufficient to raise the blood in the tube to a considerable height above the level of the heart, and is consequently more than sufficient to return the blood to the auricle of the heart. The blood did not, in Hales' experiments, in general at first rise in the tube connected with a vein more than six inches, but this he shewed to proceed from the easy escape of the blood by lateral communicating vessels, for when the other large veins were tied, or when they became fully distended with blood, that fluid sometimes rose in the tube connected with a large vein to a height of three or four feet. M. Poiseuille* demonstrated, in a still more satisfactory manner, the action of the pressure of the heart on the blood in the veins by means of the bent tube with which he measured the pressure of the arterial blood: and this fact is proved in an equally convincing manner by Magendie's experiment of isolating the principal artery and vein from the other parts of the limb of an animal, in which it was found that the flow of blood from the vein is immediately stopped by pressure or ligature of the artery. It is scarcely necessary, in order to obtain a proof of this fact, to have recourse to the vivisection of animals, for in common bleeding from the arm, the flow of blood from the vein will be found to be immediately influenced by the state of the artery, and even without the division of a vein, it is easy to observe the action of this force of impulsion which drives the blood onwards towards the heart in any of the superficial veins of the arm by the application of external pressure, a mode of illustration successfully adopted by Harvey in his explanation of the course of the blood. These very simple experiments are looked upon by some as quite sufficient to demonstrate the proposition that the blood is moved in the veins by an impulsion from behind, and that that impulsion is derived from the action of the heart; while others, not satisfied with this explanation, have endeavoured to point out additional forces as contributing to the progressive motion of the blood in the veins.

The larger veins are, like the arteries, highly elastic, and they are generally regarded as stronger proportionally to the thickness of their coats than the arteries. This elasticity belongs chiefly to the external cellular coat, for a middle fibrous coat is not apparent in most of the larger healthy veins, and in those rarer instances in which it is apparent, it is very much thinner than in the arteries. The smaller or capillary veins appear also to be possessed of some degree of irritability, for they have been seen to contract on the application of a stimulus in the web of the frog's foot by Drs. Thomson and Hastings. This, however, occurs much more rarely than the contraction of the small arteries. It has been remarked that in some animals muscular fibres are prolonged from the auricle upon the adjoining part of the vena cava; and Spallanzani, M. Hall, Flourens,* and others have recorded the fact of the rythmic contraction of parts of the great veins adjoining the auricles. But, excepting in these situations and in the caudal heart, observed by M. Hall in the Eel, muscularity of the veins cannot be considered as having any effect in promoting the flow of the blood in these vessels.

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* Magendie's Journ. vol. x.

The progressive motion of the venous blood takes place with little force, and is therefore subject to considerable variations from external pressure. Thus the flow of the blood may be much accelerated by raising a limb, or retarded by keeping it in the depending posture from the mere effect of gravitation, and the common practice of making a person who is bled in the arm call the muscles of the arm into action during the operation, is a sufficient proof that the pressure of the muscles may be the means of accelerating in a considerable degree the venous circulation,—an effect obviously dependent on the disposition of the valves. Gravitation or muscular action are, however, only occasional causes of the acceleration of the flow of blood in the veins, and both, but particularly gravitation, may in some instances offer an obstacle to its progress.

There are some physiologists who believe the blood to be drawn through the veins towards the heart by a power of suction which operates from the side of the heart or chest. The remarks we have already made in treating of the arterial and capillary circulations render it unnecessary for us to revert in this place to the arguments employed by those who have supported the above view, merely on account of their belief in the inadequacy of the heart's force to maintain the complete circulation; we shall only now state the direct experiments or reasonings by which it has been attempted to be proved that a *vis à fronte* or suction power draws the blood towards the centre of the circulation. We have already, in a former part of this article, stated our reasons for believing that the elastic power of the heart itself is not attended with any production of an appreciable force sufficient to draw the blood into its interior.

The facts which relate to the supposition that the chest or lungs become, during their motions in respiration, the source of a suction power which acts on the venous blood may be suitably considered under the first part of the fourth division of this article, viz.

IV. THE RELATION OF THE CIRCULATION TO OTHER FUNCTIONS.

1. *Respiration.*—Of the opinions of those who attribute the suction of the blood through the veins to powers within the chest, there are chiefly two which have of late years attracted attention,—those namely of Dr. Carson of Liverpool,* and of the late Sir David Barry.†

According to Dr. Carson the lungs are of a highly elastic nature, and are kept in a state of forced distension by the pressure of the atmosphere which enters them when the chest dilates. The lungs would collapse or fall away from the walls of the chest but for the force with which they are distended, and there is thus a tendency to the production of a vacuum within the chest or to a diminution of the pressure on the exterior of the heart, in consequence of which the blood is forced or drawn into the heart and chest on the same principle that fluid enters the mouth in the act of sucking.

According to Sir D. Barry, at each inspiration of air into the chest the lungs are not sufficiently expanded to fill the whole of the chest, or there is, in consequence of the expansion of the walls of the chest, a less pressure within the chest than on its exterior, and the blood is propelled through the veins communicating with the heart by the external atmospheric pressure.

Neither Dr. Carson nor Sir D. Barry state, in a sufficiently explicit manner, how much of the force impelling the blood through the veins they conceive to be of the nature of suction: they both admit that the greatest part of this force belongs to the heart or *vis à tergo*, but they yet state distinctly their belief that the suction power is an important cause of the motion of the blood throughout the whole venous system. The works of both these authors are replete with interesting remarks on the circulation in general, and more especially on the flow of blood through the veins. The direct experiments, however, in support of their opinions are comparatively few and inconclusive. Dr. Carson shewed that the lungs are always during life in a state of forced expansion, and estimates the pressure which the lungs of the sheep are capable of sustaining, when in the expanded condition, as equal to a column of seven inches of water. Sir D. Barry observed, in experiments made upon horses, that when one end of a tube is introduced into the jugular vein, and the other extremity rests in a vessel containing water, the water rose during each inspiration some length in the tube, and sank again during expiration, distinctly indicating the diminished pressure existing within the chest at the time of the rise of the water, and proving that the flow of the blood in some parts of the veins may be accelerated during inspiration from the same cause. Poiseuille,‡ by the employment of the instrument for measuring the pressure of the animal fluids, to which allusion has already frequently been made, has confirmed Sir D. Barry's statement, that the diminished pressure within the chest, at the time of inspiration, is such as to affect the flow of blood in the jugular vein, and to draw it in some degree towards the heart. In many persons, particularly the young and those of a thin habit of body, the jugular veins in the neck are frequently very distinctly seen to become full during expiration, and to be rapidly emptied and collapsed during inspiration,—a fact which shews clearly enough that the blood passing through this vein enters the chest most easily when that cavity is dilated. The position, however, of the body has a very considerable influence on this rapid evacuation of the jugular veins in such instances. Again, there are several direct experiments upon animals which are much opposed to the views at present under consideration.

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* Annales des Sciences Natur. tom. xxviii. p. 65.

* Inquiry into the Causes of the Motion of the Blood, &c. Liverpool, 1815.

† Experimental Researches on the Influence of Atmospheric Pressure upon the Progression of the Blood in the Veins, &c. Lond. 1826.

‡ Loc. citat.

Dr. Arnott[*] has shewn very successfully that such a power as that supposed to aid the venous circulation could have very little effect in promoting the flow of fluids through soft tubes, which collapse as easily as the larger veins do, because not more than an inch of fluid at the most can be drawn through one of them by a syringe, without its sides being brought together so as to close the mouth of the syringe, and this objection is in no way removed by the circumstance that the veins are kept open by the *vis à tergo* of the heart, because even although they should be open, a *force from before*, to adopt the incorrect expression frequently applied to a suction power, if strong enough to make any impression on the flow of the blood, would act, to a certain amount, just in the same way as if no force from behind existed; that is, it would tend to make the sides of the vessel come together, and would thus offer an obstacle to the further progress of the blood.

In repeating some of Barry's experiments, Mr. Ellerby[†] found that when he introduced a tube into the jugular vein of an ass for two or three inches only, there was no suction exerted through it, but that the fluid in which its further extremity was immersed rose only when the tube was thrust eight or nine inches into the vein so as to reach the chest, in which case, of course, the vein was held open by the rigid tube, and the suction power was enabled to act through it to an extent which does not take place in the natural state of the jugular vein. Messrs. Ellerby and Davies[‡] also found that the venous circulation was for a short time not materially impeded by opening the chest or the introduction of tubes into it through the parietes. It must be apparent to every one that the suction power or *vis à fronte* can exert little, if any, force of traction on the blood in the large or superficial veins of the limbs, for on making pressure upon the trunks of one of these, so as to prevent the action of the *vis à tergo*, we find that if the limb is at rest the motion of the blood in the part next the heart is wholly arrested. But if, while we maintain the pressure on the vein at one place we empty the vein for some way towards the heart, close the vein on the side next the heart, and then remove the pressure from the remote situation, the blood is at once impelled through the portion of the vein which had been emptied, by the force of the heart alone. Messrs. Ellerby and Davies have shewn that the same phenomena, or the absence of a *vis à fronte* and evidence of a *vis à tergo*, attend the flow of blood in the largest veins even, which are situated in the immediate neighbourhood of the chest; for after the application of a ligature upon the vena cava inferior, it was found that the part of this vein between the ligature and the chest was not emptied towards the heart, and that when the part of the vena cava in the immediate vicinity of the chest was emptied, and pressure then applied at the entrance of the vena cava into the auricle, the blood rose to fill the emptied portion of the vena cava, although no suction power could in this place operate. It was also found that no fluid rose in the remote extremity of a tube introduced into the femoral vein.[*] These experiments shew that a suction power, whether produced in the way supposed by Dr. Carson, or in that stated by Sir D. Barry, can have very little effect in promoting the flow of blood in the veins,—a conclusion which is rendered still more certain from some other general considerations, such as the following:

1. The whole of the vessels belonging to the pulmonary circulation are placed within the chest, and consequently the flow of blood in the pulmonary veins must be independent of any suction power connected with respiration.[†]

2. In the fœtus, as there is no pulmonary respiration, both the pulmonary and systemic venous circulations go on without any assistance from a suction power. And

3. In the portal circulation of the higher animals and in the venous circulation of fishes breathing by gills, as well as of those reptiles in which air is forced into the lungs by a process of deglutition, there can be no aid derived from a suction power.

We have already, in our description of the varieties of form in the circulatory organs of animals, adverted to the intimate relation which very generally subsists between the structure and functions of the organs of circulation and respiration. We shall now mention a few other circumstances connected with the functions of circulation in the adult human body, which seem to depend upon this relation of the motion of the blood to the respiration.

The influence of the mechanical operations of respiration is not confined to the venous circulation, for it has been shewn by direct experiment that the force of the blood in the arteries varies also from the same cause, being greater during expiration than during inspiration. This greater force of the blood in the arteries during expiration, known to Haller, Lamure, and Lorry, was proved by the experiments of Hales, Poiseuille, and Magendie[‡] formerly mentioned.

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[*] Elements of Physics, vol. i.

[†] Lancet, vol. xi. p. 326.

[‡] Lancet, vol. xi. 606.

[*] See also Macfadyen's Remarks, Edin. Med. and Surg. Journal, vol. xxii. p. 271; Carus in Meckel's Archiv. iv. p. 413; and Remarks in the Edin. Journ. of Med. Science, vol. ii. p. 462.

[†] See the late Prof. Turner's Essay on the Motions and Sounds of the Heart. Med. Chir. Trans. of Edin. vol. iii.

[‡] Journ. de Physiol. vol. i.

It is very probably occasioned in part by the assistance which the ventricular systole receives from the collapse of the parietes of the chest at the time that the air is expelled from that cavity, and in part by pressure of the parietes of the chest upon its contents, and through them upon the trunks of the larger arteries. During inspiration the pressure must be, to a certain amount, removed from the larger arteries, and consequently the current of blood through them at that period will be less forcible and less rapid.

The well-known fact that rupture of aneurisms of the large arteries and effusion of blood within the cranium in apoplexy are more liable to occur during straining and other muscular efforts associated with forcible expiration, is a further illustration of the fact that the arterial pressure is greatest at the time of the collapse of the parietes of the chest.

The relation of the force and frequency of the pulse to the activity of the respiration is an interesting subject connected with the facts at present under consideration.* In many persons, in ordinary and tranquil respiration, the force and frequency of the pulse vary perceptibly during inspiration and expiration, and in these persons, when the respiration is more forcible than natural, the pulse indicates very distinctly by its changes the varying states of the chest. During an unusually long and forcible inspiration the beats of the pulse are more rapid and weaker, and during a succeeding complete expiration, or even while the chest is kept expanded, the pulse is more full, strong, and slow. Some individuals have the power of occasioning an intermittent pulse, and some of causing the action of the heart to cease even by forcible exertion of the expiratory muscles. We think it probable that it may have been in this or some similar indirect manner that the action of the heart was arrested in Colonel Townsend's case, described by Dr. Cheyne in his work on the English malady, and very often referred to as a proof of the possession by Colonel Townsend of a voluntary power of influencing directly the heart's action.

There is in general a very constant proportion in the ordinary state of the circulation between the number of the beats of the pulse and the frequency of respiration. The average number of respirations in a healthy person may be considered as from 15 to 20 in a minute, and taking the number of the pulse in the same time at from 72 to 75, this makes one complete respiratory motion for nearly four beats of the heart. The force and frequency of the heart's action and consequent state of the pulse are well known to be considerably influenced by very slight muscular efforts, as well as by changes of position of the body even; but it is not observed that the respiration becomes invariably more or less hurried in a corresponding degree with an increased or diminished frequency of the pulse. In very violent exercise, it is true, and more particularly in rapid motions which give rise to a great and immediate increase of the frequency of the heart's action, the respiration becomes hurried and forcible, or there is panting; but, on the other hand, it does not appear that the gradual changes of the pulse, which are liable to occur from one period of the day to another, are accompanied by corresponding variations in the frequency of respiration; and again, when by a voluntary effort we breathe very hurriedly, as for example, from 80 to 100 times in a minute, the frequency of the pulse is not increased by more than 8 or 10 beats in a minute.*

Some physiologists hold the opinion that the motion of the blood in the capillaries of the lungs and the system is considerably influenced by the chemical changes which the blood undergoes in its passage through the minute pulmonary and systemic vessels. We are not acquainted with any facts or experiments which shew that the systemic capillary circulation is immediately dependent upon the change of the arterial into venous blood: on the contrary, such an opinion is much opposed by the facts that a free circulation of imperfectly arterialized blood takes place in the fœtus before birth, as well as in many children after birth affected with malformations of the heart or greater vessels, and that a completely venous blood circulates through the system in hybernating animals when in the state of deepest torpidity. There are, however, several circumstances which appear to justify the opinion that the motion of blood through the pulmonary capillaries has a more immediate dependence on the change of arterialization.† In all those circumstances which cause imperfect respiration and prevent the accustomed necessary arterialization of the blood, or in approaching asphyxia, it seems to follow from the experiments of Dr. Kay, Alison, and Reid, that there occurs from the very first commencement of the symptoms of impeded respiration, a diminution of the quantity of blood which passes through the pulmonary capillaries. There is thus produced from the first commencement of non-arterialization of the blood an accumulation of venous blood in the pulmonary capillaries and arteries, but it is equally well proved that a certain quantity of venous blood does, as Bichat shewed, gain the left side of the heart and permeate the arterial system. As the symptoms, however, of suffocation or asphyxia become more urgent, the accumulation of blood in the pulmonary artery on the right side of the heart and in the systemic veins gradually increases, until by the time that the involuntary motions of respiration have ceased, there appears to be a complete stagnation in the lungs, although the heart continues to beat a little longer. During the occurrence of these changes the action of the heart also is no doubt gradually becoming weaker, a circumstance which may very probably contribute to the stagnation of the blood in the lungs, but there is good reason to think that the motion of the blood is first arrested in the pulmonary capillaries.

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* See an interesting Essay by Hering in Tiedemann's Zeitschrift, vol. v.

* See an account of the interesting experiments by M. Roulin on the variations of the pulse at different heights. Magendie's Journ. Jan. 1826.

† See Dr. Alison's Remarks, loc. cit.

The state of our knowledge does not, it must be confessed, permit us to offer a satisfactory explanation of the cause of the above-mentioned phenomena. We have already stated reasons against regarding the stagnation of the blood in the lungs in asphyxia as attributable to a loss of the supposed vital power of motion belonging to the blood in the capillary vessels: and we think it quite as just to regard the stagnation as the effect of over-stimulation and constriction of the minute vessels of the lungs by the dark blood, as to attribute it, in the manner some have done, to the deficiency of that stimulation which arterial blood, without any good reason, is presumed by them to give to the small vessels.

2. *Circulation within the cranium.*—The limits of this essay do not permit us to do more than allude very shortly to the nature of the circulation within the cranium,—a subject, in some respects, nearly related to the facts just stated, and of great importance from the general dependence of the state of the cerebral functions upon the quantity and force of blood which flows through the brain.

The bloodvessels within the cranium are differently situated from those in other parts of the body in this respect, that they are removed from the influence of atmospheric pressure. In consequence of the unyielding nature of the skull, and its being closed on all sides, excepting at the places where the nerves and bloodvessels pass through the bones, the cavity of the skull must necessarily be equally full at all times; and the spinal canal is in the same predicament.

The whole quantity of fluid or solid matter, then, within the cavity of the cranium and spinal canal must be always the same; or, during the circulation just as much blood must issue as enters it, and it is physically impossible to increase or diminish the whole quantity contained in the brain by increased pressure, by opening of an artery or vein or any other means. It was shewn by various well devised experiments performed by the late Dr. Kellie,* that in animals bled to death, while the rest of the body was exsangueous, the brain retained its usual appearance so long as the vault of the cranium was entire, but that a perforation of the skull, such as to allow the atmospheric pressure to act upon the brain and bloodvessels of the head, caused the evacuation of blood from the head as from other parts of the body.

While the whole bulk of the contents of the cranium, however, must necessarily remain the same, yet the relative quantity of arterial and venous blood may vary within a short space of time, the pressure exerted by the blood in the vessels may be greater or less according to circumstances; and there may occur within the skull local determinations or partial distributions of the blood. When from rupture of a bloodvessel, inflammation, suppuration, or other causes, blood, serum, or pus are effused into the cavity of the cranium, the circulating blood must be diminished in quantity; when there is any obstruction to the return of the blood by the jugular veins, the pressure of the blood entering by the carotid artery is proportionally greater; and when the arteries which supply blood to the brain are obstructed, or the heart's action is less forcible than usual, the pressure on the brain must be diminished in a corresponding degree.

In the natural state of the circulation the pressure exerted by the blood circulating through the cranium is subject to regular alternations of increase and decrease from the effect of the heart's action and the motions of respiration. When the brain of man or of animals is exposed by the removal of a part of the skull, it is seen to be slightly raised at the exposed part at each arterial pulsation, and more perceptibly during each expiration. The brain falls again during each succeeding inspiration, but does not sink below the level of the skull. These motions may also be perceived at the fontanelles of the infant's head, where the bony parietes of the skull are deficient. In the closed state of the skull, for the reasons previously mentioned, it is obvious that there can be no motions similar to those observed in the brain when exposed, but nevertheless the brain must be more forcibly pressed upon by the blood at these times than at others. Haller, who had observed these motions, conceived the depression during inspiration to be caused simply by the ease with which the blood enters the chest at that time, and attributed the swelling of the brain during expiration to the obstacle then offered to the descent of the blood through the jugular veins. It seems, however, probable that the greater fulness of the arteries during expiration may also contribute to raise the brain at the time when the collapse of the walls of the chest occurs: for Magendie observed, that when a ligature was put upon the jugular vein, the blood which issued from this vein by an aperture above the ligature, flowed with greater force during expiration, shewing that increased arterial pressure during expiration was continued through the capillaries into the veins. Sign. Ravina, who made a very extensive series of experiments upon these motions, found that when the brain has been depressed during inspiration, it again swells, although no expiration succeeds, but that when raised during expiration, it does not again sink, if inspiration does not follow.

3. *Influence of varieties in the distribution of arteries and veins upon the circulation.*—As connected with some of the above-mentioned facts, and exerting a considerable influence in modifying the circulation of the blood in particular states of the animal economy, we may here mention a few of the more remarkable varieties in the distribution of the arteries and veins, together with the uses they have been supposed to serve in different animals. The varieties of form in the larger arteries may be considered under two heads; *a*, simple tortuosity; and *b*, sudden division into many small branches.

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* Edin. Med. Chirurg. Trans. vol. i.

a. One of the best examples of the first of these varieties, which are by no means uncommon in animals, occurs in the spermatic arteries of the bull. Two reasons have been assigned for the existence of this, viz. 1, to allow, by the greater length of the vessel, for the stretching of parts, as in the arteries of the lips; and 2, to diminish the velocity of the blood passing through the tortuous vessel, from the longer course and greater incurvation.* Increased friction, which must be the consequence of greater length of the artery, will diminish the velocity of the blood through the whole vessel, and besides this, a given particle of blood passing through a tortuous vessel will arrive later at its destination, in consequence of the longer course it has to run through; but if we regard the fluid in the arteries as every where subjected to pressure, it is very doubtful that the increased curvature can be the source of any considerable retardation by diminishing the force communicated by the impulses of the heart.†

b. The sudden division of an artery into many small branches may take place with or without tortuosity or a plexiform arrangement; the primitive vessel disappearing or persisting, but in most cases when present, diminished in size. The most remarkable examples of this peculiarity of the arterial system are the following. 1. The intercostal and lumbar arteries of the Cetacea in the posterior part of the chest, and in the vertebral canal and the caudal artery of the same animals, which are tortuous and plexiform. 2. The brachial artery of the Porpoise, which divides at once into more than forty plexiform branches. The primitive trunks disappear, and five or more vessels emerge from the distal end of the plexus. The uterine and vesical arteries of the same animal are much divided, but not plexiform.‡ 3. The subdivided brachial and crural arteries of the Bradypus tridactylus, Lemur tardigradus, L. gracilis and L. tarsius; and the same arteries, as well as the caudal arteries of the Myrmecophaga didactyla and M. tetradactyla. 4. The arteries of the legs of the Swan, Goose, and Turkey divide into several long branches, which anastomose with one another.§ 5. The rete mirabile of Galen on the internal carotid of many quadrupeds, and the rete mirabile on the common carotid of the Frog. 6. The rete mirabile of Hovius on the ophthalmic artery of some animals, the Seal for instance. 7. The mesenteric arteries of the Sow at their commencement. 8. The subcutaneous arteries of the Hedgehog.

The uses of these very various forms of arteries it must be confessed is very little known. Some of them may, like other peculiarities in animal structure, and more especially those belonging to the vascular system, be remains of the fœtal condition of the arteries in which they exist.* The most common opinion entertained as to their effect on the circulation is that they retard the velocity of the blood, and render its flow more uniform, thus preventing the parts supplied by them from being affected by sudden changes.† Other secondary consequences of the diminished velocity occasioned by these peculiar structures have been imagined, as for example, 1, diminished rapidity and greater durability of muscular contraction, as in the Sloths;‡ 2, security against obstruction of the circulation from pressure, as in climbing animals which cling long and forcibly to branches of trees;§ 3, or these plexuses have been regarded as intended to increase the capacity of the arterial system, and to serve as reservoirs for blood, as may be the case in the Cetacea.‖ In some of the above-mentioned animals the tortuosity or multiplied divisions of the arteries are accompanied by a similar condition of the veins, as in the Porpoise.

The most remarkable variety in the form of the venous system, and the one to which a use may be most easily assigned, is the large dilatation of the vena cava inferior in the neighbourhood of the liver, which occurs in those animals which from their mode of life are in the habit of remaining long under water, such as the Seal, Otter, and Diving Birds. The purpose of the venous sinuses in these situations is manifestly to allow of the accumulation of venous blood in the vena cava without an unusual distension of the right side of the heart and bloodvessels leading into it and from it, which is the effect of long submersion or impeded respiration in animals unprovided with this peculiarity of structure. The venous and arterial plexuses of the Cetacea very probably serve the same purpose. The muscularity of these sinuses alleged by some must have the effect of emptying them more easily than would be accomplished by the *vis à tergo*.

4. *Influence of the nervous system upon the circulation.*—It is a very general opinion among physiologists that a considerable influence is exerted by various parts of the nervous system upon the function of circulation as a whole, and through it upon the different processes of the economy concerned with nutrition, as digestion, secretion, growth, animal heat, &c. There is some difficulty, however, in ascertaining the exact relation which subsists between particular parts of the nervous and circulatory systems. It is manifest that in many instances the circulation in the bloodvessels is modified by a nervous influence which operates on the heart alone, while in others it is affected by an alteration of the vital powers of the bloodvessels themselves. We refer the reader to the articles CONTRACTILITY and HEART for an account of the modifications to which the circulation is liable from the operation of nervous influence on

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* J. Hunter.

† Müller's Physiol. vol. i. p. 198.

‡ See the accounts of these varieties by J. Hunter in the Phil. Trans. Sharpey, Meeting of British Scient. Assoc. in Edin. Sept. 1834. Breschet, Annal. des Scien. Natur. 1834. Baer, Nov. Act. Nat. cur. 1835.

§ Cuvier, Leçons d'Anat. Comp. vol. iv.

* Baer, loc. cit.

† Barclay on the Arteries, p. 36.

‡ Carlisle, Phil. Trans. 1800. Roget, Bridgewater Treatise.

§ Vrolik.

‖ J. Hunter, loc. cit.

he heart alone. We shall only remark in his place that although the heart may be excited to contraction by the direct stimulation of its muscular substance, and although the effect upon the heart's action of bodily exertion, of emotions of the mind, and of severe injuries of the brain and spinal marrow, all of which can be supposed to act upon the heart through the nerves only, are undoubted; yet it is well ascertained that the heart cannot in general be excited to contraction by the direct stimulation of its nerves, and that its action may be regarded as automatic to a certain degree, and little dependent upon the immediate transmission to it of any nervous influence from the cerebro-spinal or ganglionic nervous systems, since the rythmic contraction of the heart continues to go on for a time in some animals after the division of its nerves, and in others even after its complete separation from the body. It has also been frequently found that after the complete destruction of the brain and spinal marrow of an animal the circulation of the blood can be maintained for some time by means of artificial respiration,—an experiment which proves that the motion of the blood in the vessels is not immediately dependent upon nervous influence.[*]

Many circumstances, however, seem to shew that the state of the vessels, and in consequence of this the velocity and force of the blood, are susceptible of very considerable modification from local affections of the nerves belonging to the part in which they may have been observed to occur, or from general alterations of the nervous powers of the system. It is probable that nervous influence operates much more powerfully in modifying the circulation through the small than through the large vessels, indeed we know of no direct satisfactory experiments which demonstrate the effect of nervous influence upon the larger arteries exclusively.

The experiments which seem to prove most satisfactorily the influence of the nervous system on the circulation in the small vessels are those performed on cold-blooded animals by Legallois,[†] W. Philip,[‡] Flourens, and particularly those of Marshall Hall,[§] the general result of which may be stated as the following: that after the destruction, whether sudden or gradual, of the brain or spinal marrow, the flow of blood in the remote parts becomes more languid and is gradually more and more circumscribed, while the action of the heart continues, and its power seems not to be diminished in a proportional degree. But in such experiments as those just mentioned, performed in general in cold-blooded animals, it must be at all times exceedingly difficult to find an accurate mode of measuring the force of the heart, and consequently they cannot be regarded as affording sufficient evidence that there did not occur along with the languid state of the circulation a certain diminution in the heart's power. They do not at least entitle us to conclude that the decreased velocity and stagnation of the blood in the remote parts is caused mainly by the loss of the vital powers of the capillary vessels, for these changes of the circulation may in a great measure be the effect of other causes, as the loss of power of the heart, and that more permanent alteration of the textures which very probably accompany the severe injury done to the body. On the other hand it may be remarked that the coldness and impaired nourishment common in palsied limbs, the known increase or diminution of the various secretions from mental emotions, and direct or sympathetic affections of the nerves belonging to the glands or other secreting organs, the phenomena of blushing, erection, inflammation, and the like are all very direct and satisfactory proofs that the small vessels and the capillary circulation may be influenced by affections of the nerves. As a further confirmation of this may be mentioned, 1, the inflammation and other consequences of the division of the fifth pair of nerves which occur in the eye; 2, the statement of some, as Treviranus, that the division of the nerves of the leg of a frog impedes the circulation: 3, the assertion by others, as Baumgärtner, that after the division of the nerves or the destruction of the spinal marrow, the peculiar oscillations which he, along with Doellinger and Kaltenbrunner, has observed to precede the formation of new blood-vessels do not occur; and 4, the observations of Nasse, which are stated to shew that the reunion of wounds is retarded or put a stop to by the division of the nerves belonging to the wounded part. Krimer,[*] whose experiments on this subject are numerous and remarkable, states that the circulation was always much impaired by the abstraction of nervous influence from the division or ligature of the nerves; that the jet from the femoral artery of a quadruped was much less strong after the division of the crural nerve; that the capillary circulation of the frog's web ceased soon after the nerves were cut or tied; that the arterial blood passed through the systemic capillaries without undergoing its proper change into venous; and that salt did not produce the accustomed effect of dilating the capillaries when the nerves of the part were injured, but that these effects were induced when galvanic irritation was applied to the divided nerve.

In reference to these experiments it may be remarked that most of them are at variance with experiments of a similar nature performed by others, more especially those of Haller, Spallanzani, Whytt, Fontana, Legallois, W. Philip, Flourens, and M. Hall, none of whom remarked so immediate and complete a stoppage of the circulation from removal of the nervous influence. Again, in palsied limbs the circulation is frequently little or not at all disturbed, and sometimes the secretions, natural growth of parts, and reunion of wounds have been found to be little impaired by injuries of the nerves. We may therefore form the conclusion, that although the circulation in the small vessels is obviously liable to be modified by the state of the nerves in their neighbourhood, or perhaps by affections of the nervous system in general, there is no reason to consider the capillary circulation as more immediately dependent on nervous influence than the action of the heart.

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[*] We refer here to the experiments of Haller, Whytt, Fontana, Spallanzani, Legallois, W. Philip, Clift, Flourens, and Müller; Humboldt, Fowler, Brachet, Treviranus, Weinhold, &c.

[†] Expér. sur le Principe de la Vie.

[‡] Exper. Inquiry into the Laws of the Vital Functions.

[§] Loc. citat. p. 99.

[*] Physiologische Untersuchungen. Leipzig, 1820.

Bibliography.—We have deemed it advisable to reserve our historical sketch of the discovery of the circulation and the knowledge of that important portion of physiology to this part of the article, thereby consulting brevity in uniting it with the literature of the subject.

The Chinese have been conceived to have entertained correct notions of the circulation before they had any intercourse with Europe,—a supposition, the erroneousness of which is sufficiently demonstrated by their description of the commencement of the circulation of the radical humours and vital heat at three o'clock in the morning, their passage through the lungs in the course of the day, and termination in the liver at the end of twenty-four hours, as well as by the different manipulations practised by them in the operation of venesection.

In the time of Hippocrates and Aristotle, although the principal bloodvessels were described—apparently from dissection of animals,—the course of the blood appears to have been wholly unknown.

Towards the end of the second century Galen describes accurately the distribution of many of the bloodvessels in the lower animals. He appears also to have known the anastomoses of the arteries and veins, and the structure and uses of the foramen ovale in the fœtus, but his works afford no evidence of his having known the course of the blood in either the pulmonic or the systemic circulations. He desribed the arteries as arising from the heart, the veins from the liver; and some of those passages of his works in which it is alleged that the circulation of the blood is pointed out, are either inconsistent with one another, or are believed to have been introduced at a later time than Galen's. Galen believed that the blood passed through the septum of the ventricles; he knew that the arteries contained blood, but he believed its motion to be of an oscillatory kind. (De usu partium, l. iv., vi., & vii., and his treatise on the question—*an sanguis in arteriis naturâ continetur?*)

The authors of a more recent date, in whose works it has been supposed that the circulation was described, are Servetus, Columbus, and Cæsalpinus. After the revival of letters, the great anatomist Vesalius of Brussels, in 1542, had examined more minutely than his predecessors the connections of the arteries and veins: he mentions the valves of the veins, the difference between the veins and arteries, and describes the valves of the heart. He seems to have known that the blood was propelled into the arteries by the heart, and demonstrated by a more direct experiment than Galen's, that the arterial pulse depends on the systole of the heart. (De corporis humani fabricâ, fol.; and Opera Omnia, curâ Boerhaave.)

Servetus, the victim of religious persecution in 1553, is one of those in whose writings we find the first dawn of part of the discovery of Harvey, for he very distinctly at one place refers to the pulmonary circulation. The vital spirit (blood) passes by the arteries into the veins by their anastomoses. The blood cannot pass from the right into the left auricle on account of the closed nature of the septum auricularum; in the adult it must go through the lungs, where it is charged with the vital spirit obtained from the atmospheric air, and then returns to the heart. He further held that the pulmonary artery and vein from their large size must have some other use than the nourishment of the lungs merely. De Trinitatis Erroribus. Basil, 1531.

Columbus, Professor at Padua and Rome, six years after the publication of the work of Servetus, published the discovery of the lesser circulation as his own. He describes it more clearly than Servetus does, and held that the blood returning from the lungs is not mixed with vital spirit, but is quite pure. Libri xv. De re anatom. Venetiis, 1559.

Cæsalpinus of Arezzo, Professor at Pisa, gave, in 1583, a more detailed description of the pulmonary circulation than any of those who preceded him, and in two parts of his work expresses himself in such a manner as to shew that he had some idea of the systemic and double circulation. Other passages in his works are, however, quite inconsistent with a correct knowledge of the course of the blood, and, although we find this course more nearly indicated in the writings of Cæsalpinus than in any others before the time of Harvey, he does not seem to have added much, if any thing, to the knowledge possessed by those who preceded him, but rather to have applied, and without acknowledgement, the observations of Vesalius, Fallopius, Servetus, and Columbus, to the explanation of the circulation.

The fœtal circulation seems to have been examined with great attention by the anatomists of the sixteenth century. Galen had already been acquainted with the foramen ovale, and also knew, though less perfectly, the ductus arteriosus. Fallopius described the ductus arteriosus exactly, so also did Vesalius and Aranzii; and after this Botallus appropriated to himself the discovery of both the foramen ovale and ductus arteriosus. Vesalius discovered the ductus venosus which was figured by Fabricius and Eustachius. Fabricius ab Aquapendente made the discovery of the valves of the veins and published it in 1603: it is surprising that knowing their structure so perfectly as he did, he should have continued ignorant of their uses, and strictly attached to the older erroneous opinions regarding the circulation.

Dr. William Harvey was born at Folkstone in Kent, and studied under Fabricius at Padua from 1598 to 1602. Learning from his master the structure of the valves of the veins, he engaged in experimental researches after returning to England, with the view of determining their uses, and in 1619, according to his own statement, taught publicly for the first time the doctrine of the double circulation of the blood, which he had demonstrated by his investigations. He did not publish any history of this discovery until after the lapse of nine years, during which he had carefully examined his doctrines and experiments. This appeared in the Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus, first published at Frankfort in 1628.

Among the contemporaries of Harvey who supported his views, the following authors are remarkable.

Werner Rolfink, Professor at Jena, one of the first to adopt the new view, published two years after the publication of Harvey's work.

Des Cartes upon two occasions supported Harvey's views, viz. in 1637 and 1643, having been answered by Plempius.

John Walæus, Professor at Leyden, may be regarded as one of the most original of those who adopted and defended the new view. In 1640 he published two letters, addressed to Thomas Bartholin.

Herman Conring of Hermstadt.

James de Back, Amsterdam, 1649.

John Trullius, 1651, Rome.

George Ent of London.

Riolan was the only one of his opponents whose objections Harvey thought it worth while to answer. This he did in two additional Exercitationes, which are published in the Leyden edition of his works, 1737. In a journey which Harvey made to Germany, he endeavoured to demonstrate his views to Hoffman, but without success. In 1652 Plempius acceded the merit of discovery to Harvey, and adopted his views of the circulation. Harvey died at the advanced age of 79, in the year 1657, after having had the satisfaction of seeing his views generally adopted by the best-informed anatomists and physiologists, and after having enjoyed the glory due to so great and valuable a discovery.—The best edition of Harvey's treatise on the Circulation is that to be found in the edition of his works published by the London College of Physicians, in 4to.

About this time the experiment of transfusion, proposed some time previously, seems to have been first successfully performed by Dr. Timothy Clarke, Boyle, and Henshaw, as also by the celebrated Lower at Oxford, in 1660, affording additional proof of the correctness of the views of Harvey.

Although the double course of the blood through the pulmonic and systemic circulations was fully demonstrated by these investigations, the direct passage of the blood from the smaller arteries into the veins had not yet been observed.

After the introduction of the use of the microscope, this additional proof was supplied by Malpighi, who discovered the capillary circulation in the vessels on the lungs and mesentery of the frog in 1661 (Epistola de pulmonibus).

Malpighi observed the passage of the globules of the blood through the minute vessels, and thus satisfactorily proved that there is an actual transmission of the circulating blood from the arteries to the veins in both the systemic and pulmonary circulations.

Leuwenhoeck, in 1673, repeated the observations of Malpighi on the capillary circulation, and extended them to different animals, at the same time adding to their value by the discovery of the nature of the colouring particles or globules of the blood (Philos. Trans. No. 102). The structure of the minute vessels in different parts of the human body was shortly after this very fully shewn by the fine injections of Ruysch, and the analogy between the structure of the minute vessels in Man and the lower animals thus fully established.

For the history of the discovery of the Circulation, we would refer the reader to the following works. *Bostock's* Elementary system of physiology, vol. i. p. 343. *Haller's* Elementa, vol. i. p. 340. *Senac*, Traité du cœur, Introduct. p. 68. *Sabatier*, Anatomie, ii. p. 255. *Portal*, Hist. de l'anatomie et de chirurgie, t. ii. p. 468. *Sprengel's* History of medicine, French, vol. iv. p. 85. *Hecker's* Gerschichte der Medezin, *Hecker's* Lehre vom Kreislauf von Harvey, Berlin, 1831. *Barrellotti*, Dialogo sulla scoperta della circolazione del sangue nel corpo umano, Pisa, 1831.

When the course of the blood in the double circulation had been fully established by the abovementioned observers, and the views of Harvey were universally adopted, the labours of anatomists and physiologists were directed to the more minute and detailed investigation of the different processes of the circulatory function.

The works of Lower, Lieutaud, and Senac on the heart, and of Hales, Haller, and Spallanzani on the motion of the blood, were among the more important of those which appeared during the last century which contributed to advance the knowledge of our subject.

The second volume of Dr. Stephen Hales's Statical Essays, 1733, contains the history of the numerous experiments made by that ingenious philosopher, with a view to investigate the hydraulic phenomena of the circulation and the first accurate measurements and calculations of the force of the current of blood in the arteries and veins, its velocity, the power of the heart, &c.

The works of Haller on the circulation consist,

1st, of the greater part of the first and second volumes of the Elementa, containing a complete history of the structure and functions of the organs of circulation;

2d, Deux mémoires sur le mouvement du sang, &c. Lausanne, 1756: the first memoir containing the results, the second a detailed account of the experiments.

These Memoirs are also published in the Opera Minora; also, in English, Lond. 1757.

3d, Deux mém. sur la formation du cœur dans le poulet, Laus. 1758.

The work of Spallanzani, entitled Experiments upon the Circulation of the Blood, translated by Tourdes into French, Paris, An viii., and by R. Hall, M.D. into English, Lond. 1801, contains a great body of most accurate observations and experiments.

The first two Memoirs are on the circulation throughout the vascular system.

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THE END.

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